2

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

A COMPARATIVE ANALYSIS OF THE TACTICAL ROUTES SELECTED BY THE CAMMS/SHAW DECISION AID WITH TACTICAL ROUTES SELECTED BY ACTIVE DUTY OFFICERS

by

John S. Regan

September, 1990

Thesis Advisor: Samuel H. Parry

Approved for public release; distribution is unlimited.

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188
1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED		1b. RESTRICTIVE MARKINGS		
2a. SECURITY CLASSIFICATION AUTHORITY		3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited		
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE				
4. PERFORMING ORGANIZATION REPORT NUMBER(S)		5. MONITORING ORGANIZATION REPORT NUMBER(S)		
6a. NAME OF PERFORMING ORGANIZATION Naval Postgraduate School	6b. OFFICE SYMBOL OR	7a. NAME OF MONITORING ORGANIZATION Naval Postgraduate School		
6c. ADDRESS (City, State, and ZIP Code) Monterey, CA 93943-5000		7b. ADDRESS (City, State, and ZIP Code) Monterey, California 93943-5000		
8a NAME OF FUNDING, SPONSORING ORGANIZATION	8b. OFFICE SYMBOL	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER		
8c. ADDRESS (City, State, and ZIP Code)		10. SOURCE OF FUNDING NUMBERS		
		PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Including Security Classification)
A COMPARATIVE ANALYSIS OF THE TACTICAL ROUTES SELECTED BY THE CAMMS/SHAW DECISION AID WITH ROUTES SELECTED BY ACTIVE DUTY OFFICERS

12 PERSONAL AUTHOR(S)
REGAN, John S.

13 TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. Page Count
Master's Thesis	FROM TO	1990, September	123

16. SUPPLEMENTAL NOTATION
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

17 COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	CAMMS/SHAW, Tactical Optimum Path

19. ABSTRACT (Continue on reverse if necessary and identify by block number)
This thesis is an evaluation of the performance of a tactical route decision aid model that was developed by CPT Charles Shaw in his 1989 Master's thesis The decision aid was developed as a module inside the Condensed Army Mobility Management Model (CAAMS) The decision aid selects tactical routes based upon a complex methodology which consideres a number of variables in the tactical situation and the time available. The Janus(A) high resolution combat model was chosen to compare the routes selected by the decision aid against routes selected by active duty officers in two different areas of operation A measure of effectiveness was selected based on the casualty figures generated by the Janus(A) model When compared against the officer routes using the MOE, decision aid routes were more effective in one of the two areas of operation Janus(A) was also used to determine if routes the decision aid deemed as better were more effective as measured by the MOE. The study found that some of the "better' routes were actually less effective in Janus(A). The study concludes that the model needs some refinement.

20 DISTRIBUTION/AVAILABILTIY OF ABSTRACT		1a. ABSTRACT SECURITY CLASSIFICATION
[X] UNCLASSIFIED/UNLIMITED [ ] SAME AS RPT. [ ] DTIC		Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code)	22c. OFFICE SYMBOL
Samuel H. Parry	(408)646-2779	OR/Py

DD Form 1473, JUN 86 Previous editions are obselete. S/N 0102-LF-014-6603

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

Approved for public release; distribution is unlimited.

A Comparative Analysis of the Tactical Routes Selected by the CAMMS/Shaw Decision Aid With Routes Selected by Active Duty Officers

by

John S. Regan
Captain, United States Army
B.S., United States Military Academy

Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
September 1990

Author: John S. Regan

John S. Regan

Approved by: S. H. Parry

Associate Professor Samuel H. Parry, Thesis Advisor

James C. Hoffman

MAJ James Hoffman, Second Reader

P. Purdue

Professor Peter Purdue, Chairman
Department of Operations Research

ABSTRACT

This thesis is an evaluation of the performance of a tactical route decision aid model that was developed by CPT Charles Shaw in his 1989 Master's thesis. The decision aid was developed as a module inside the Condensed Army Mobility Management Model (CAMMS). The decision aid selects tactical routes based upon a complex methodology which considers a number of variables in the tactical situation and the time available. The Janus(A) high resolution combat model was chosen to compare the routes selected by the decision aid against routes selected by active duty officers in two different areas of operation. A measure of effectiveness was selected based on the casualty figures generated by the Janus(A) model. When compared against the officer routes using the MOE, decision aid routes were more effective in one of the two areas of operation. Janus(A) was also used to determine if routes the decision aid deemed as "better" were more effective as measured by the MOE. The study found that some of the "better" routes were actually less effective in Janus(A). The study concludes that the model needs some refinement.

TABLE OF CONTENTS

LIST OF FIGURES

I. INTRODUCTION

A. GENERAL

In every offensive scenario, land combat leaders of both the Army and the Marine Corps must decide where to move their forces in order to reach their objective. A host of factors may influence this decision including the mission of the force, the enemy strength and disposition, the time available, the terrain, and many others. Commanders must weight each of these factors within the context of the overall tactical situation to make their decision. These leaders carefully consider this decision as they know that the route they select will significantly affect the success or failure of their mission.

The route to the objective is so important because it helps to determine the time of arrival and the strength of the attacking force on the objective. A good route might allow the attackers to arrive on time and yet avoid much of the firepower from the enemy's covered and concealed defensive position. It could even help them to avoid detection altogether and achieve complete tactical surprise. The attacker could then bring the maximum amount of firepower to bear against the defenders at the objective. A bad route, on the other hand, might leave the attacker unnecessarily exposed to lethal enemy fires. This could squander much of his firepower thus preventing victory.

Currently officers select routes based upon both a physical reconnaissance and a map reconnaissance. The map reconnaissance of the terrain is always performed first. Map reconnaissance consists of the officer studying the features on a military map in order to select the best routes for his mission. The officer would then perform an actual physical reconnaissance of these routes in order to select the route for his unit's actual movement. However, time or security reasons often preclude a physical reconnaissance so a unit is sometimes forced to rely on a map reconnaissance alone. An effective decision aid might greatly assist these officers as they perform their reconnaissance and select the route for their unit. This is because it is often difficult to recreate all the terrain effects from the military map. For example, it is sometimes very difficult or time consuming to determine if the enemy can observe you at a particular position simply by looking at the topographic information on a map. Also, the significance of the features on a map change depending on rainfall and other seasonal factors. These features could greatly influence the speed of travel on the route. In addition, even when a physical reconnaissance can be performed, a decision aid could help to focus the reconnaissance in a particular area. This could help the leader save time and avoid premature detection while reconnaissance is being performed.

In his 1989 Master's Thesis [ref 1] CPT Charles Shaw developed such a decision aid. His thesis developed a "psychometric method for determining optimum, tactical paths for a small unit or vehicle". Briefly, his thesis demonstrated a methodology for determining an "optimal" route for a small unit and/or vehicle in a tactical environment.

CPT Shaw's methodology determined its "optimal" path based upon both the physical effects of terrain and the environment as well as the cognitive decision making process of the user. The physical effects of the terrain and the environment are available in numerous digital data bases. CPT Shaw's approach used this data and psychometric techniques in order to determine a power function value which is affected by the specific tactical scenario and the given equipment configuration. This power function then provides the means to determine the tactical movement potential of each cell. Tactical movement potential is defined as a subjective evaluation of relative tactical value of a given point. CPT Shaw then uses techniques developed by Professor Glen Lindsay of the Naval Postgraduate School which first translate the subjective evaluations of the survey into an interval scale and then into a ratio scale [ref 2:pp 1-21]. Next, he translates the ratio scale into the same scale as the physical continuum, time. Finally, the user must evaluate the importance of time or speed. In other words, how far from the quickest path can the algorithm deviate in order to find the optimum path? This tactical time evaluation is then combined with the physical traversal times in order to determine a single value mapping. The result is then optimized using Dijkstra's algorithm. This procedure will be discussed in detail in Chapter II of this thesis [ref 1:pp iii].

One of the sponsor's of CPT Shaw's research, the United States Army Corps of Engineers Waterway's Experimentation Station, is carefully considering the fielding of this type of decision aid throughout the entire Army. This fielding would mean a large commitment of Army resources including significant hardware, software, and training costs. Another potential use of CPT Shaw's algorithm is in the field of high resolution combat modeling. Currently, most high resolution models require human input of routes. If CPT Shaw's model yields routes that are sufficiently similar to "human" routes, then his model might be used as a surrogate to human/modeler inputs.

B. PROBLEM STATEMENT

This thesis will explore the effectiveness of CPT Shaw's decision aid. It will try to determine whether this decision aid provides combat leaders with a tool which could significantly help them with route selection. It will compare and analyze the routes selected by the decision algorithm over the range of possible time input values. It will also compare the movement routes selected by the algorithm with unaided routes selected by Army and Marine officers at the Naval Postgraduate School. The purpose of this analysis is to give insight into three basic questions:

- Are better routes in the decision aid truly better in a measurable way? For example, if you relax the time constraint and hold the other variables constant, is the resulting route better than or at least equivalent to the more constrained route?
- In a specific scenario, are the decision aid routes significantly better than the "unaided" movement routes chosen by Army and Marine officers stationed at the Naval Postgraduate School? The answer to this question is important because it directly impacts on the procurement question. If the CAMMS/Shaw routes are better, then the deployment of such a decision aid could increase the capabilities of current forces. If it is not measurably better, then it does not justify the significant procurement costs.
- Is the route selected by the model a good surrogate for officer selected routes? If it is similar, then it might be used in combat models.

C. METHODOLOGY

The first step in this study is to choose a procedure or environment in which to compare the routes. One method might be a field experiment where actual soldiers are used in the experiment for both the friendly and the enemy force. The advantage of this procedure is the obvious realism which lends credibility to the results. Indeed, the Army's Test and Experimentation Command often conducts such tests. However, there are several disadvantages to this procedure that preclude its selection for this study. First, this procedure is expensive because of the costs involved in assembling the men, equipment and the training area. In addition, the stochastic effects of such an experiment would greatly increase the cost. The increased cost would result because the variance in the measures of effectiveness due to individual and unit training levels as well as the combat itself might be quite large. This variance would necessitate a number of units and a large number of replications in order to obtain any reasonable statistical significance. The cost would be prohibitive. As a result, a high resolution combat model will be used to conduct the study.

There are several combat models available in the Army inventory which might be used in this study. They include the Janus(A) model, the Battalion Combat Outcome Model(BCOM), the Combined Arms and Support Task Force Evaluation Model (CASTFOREM), and others. The Janus(A) high resolution combat model was chosen for three reasons. First, it is a high resolution model that is approved by the Army Models Board. Second, CPT Shaw designed his algorithm to be compatible with Janus(A) [ref 1: p.41]. Finally, it is readily available for use at the Army's TRADOC Analysis Command at the Naval Postgraduate School. This model will be discussed in detail in Appendix A.

Next, the experiment must be designed and data must be collected. The first step in the design will be to select tactical scenarios which are doctrinally sound and appropriate for study in both models. Then, the routes from CPT Shaw's model as well as the officer routes must be obtained. A survey of officers at the Naval Postgraduate School will be used to obtain the officer routes. The routes that result from this officer survey and CPT Shaw's algorithm will then be input and run in the Janus(A). The resulting casualty figures from Janus(A) can then be compared using appropriate measures of effectiveness (MOEs) and standard statistical and graphical techniques. The entire design of this experiment is discussed in detail in Chapter III. The results of this thesis are discussed in Chapter IV. These results provide Army leaders a tool for evaluating the potential of CPT Shaw's algorithm.

II. DEVELOPMENT OF THE SHAW MODEL

A. PREVIOUS ROUTE SELECTION MODELS

1. General

Over the years a number of models have been developed to predict unit movement. Some of these models are only used in computer simulations such as the DYNTACS (Dynamic Tactical Simulation) and STAR (The Simulation of Tactical Alternative Responses) models. Other models such as the AMM (Army Mobility Management) and the CAMMS (Condensed Army Mobility Management) model are actually used by the Army in the field for mobility predictions, such as vehicle traversal speed and maneuver damage. A brief discussion of each of these models and its effect on CPT Shaw's procedure follows.

2. The Dynamic Tactical Simulation Model (DYNTACS)

The DYNTACS model is an extremely high resolution model that was developed at Ohio State from 1964 to 1971 [ref 3]. This simulation consists of a driver routine and 34 subroutines. Dynamic Programming is used to determine a unit route by minimizing the "tactical difficulty" of the route. The algorithm computes tactical difficulty using a heuristic, TD = (1 + E)T. E, the difficulty associated with each route segment, is a function of a number of factors along each route segment. These factors and their corresponding function values were determined through comparative judgements. T is the travel time for that route segment which is computed using engineering models. Shortcomings in this procedure that CPT Shaw tries to correct include the elimination of the heuristic approach and the multiplicative relationship between the cognitive (E) and the physical (T) scales [ref 1:p 5].

3. The Simulation of Tactical Alternative Responses Model (STAR)

Another model which effected the CPT Shaw algorithm is the STAR model [ref 1: p.5]. This model eliminated the dynamic programming solution technique of DYNTACS by using Dijkstra's algorithm. Dijkstra's algorithm is a standard network optimization technique which solves the single source shortest path problem. This label setting algorithm works on all graphs with nonnegative costs (tactical difficulty or time). The algorithm maintains a set of vertices S whose optimal path is known. Then, at each step it adds a vertex whose distance or cost is the shortest possible until the final vertex is reached [ref.6: pp. 203-209]. However, this model borrowed the heuristic equation from DYNTACS, TD = (1 +E)T [ref 4:p.33]. CPT Shaw saw this heuristic as a major shortcoming [ref 1:p 5].

4. **The Condensed Army Mobility Model (CAMMS)**

A mobility model provides information on the ability of vehicles or men to traverse terrain in varying conditions. This type of model does not consider the cognitive factors which are necessary to describe how a unit will move in a tactical environment. For example, a mobility model could identify "slow go" terrain, its elevation, and its vegetation, but it does integrate all these factors with the tactical situation in order to determine a tactical movement route. However, this type of model provides an excellent data base for a model with a goal of building a route selection model.

The CAMMS model is one of the leading mobility models used today in the Army. The CAMMS model was derived from the Army Mobility Model (AMM) which was developed in the late 1970's. The AMM was a large model developed for use in a mainframe computer environment. CAMMS was developed for use on personal computers by using a vehicle preprocessor and restricting movement to one vehicle at a time. Because it can be run on a personal computer, it is practical for wide use in the Army today. This model is used by various agencies throughout the Army to include the United States Military Academy, the Training and Doctrine Command,the Army Research Institute, the United States Army Europe, and others. CPT Shaw used this model as a key part of his route selection methodology [ref 1:pp 7-9]. His algorithm is now a subroutine of the CAMMS model at TRAC-Monterey.

The CAMMS model uses extremely high resolution terrain data. Surface elevation, soil composition, and vegetation data for 100 meter cells are components of the model's data base. The model is also capable of evaluating the effect of various climate conditions on movement so that the seasonal effect of weather on the terrain can be modeled. This model uses these data and information about a specific vehicle to predict the vehicle's ability to move across the terrain and the speed of that movement.

The CAMMS model provides an excellent framework for the development of this new route selection methodology.

B. COGNITIVE FACTORS EFFECTING ROUTE SELECTION

1. General

CPT Shaw determined a data base (CAMMS) containing the key physical traits necessary for his route selection algorithm. The next step was to bring the human decision making process into the equation, a difficult task. In making their route selections, officers simultaneously consider a large number of variables. CPT Shaw had to decide which variables were critical to the decision making process and how to weight or scale these variables. These weights or scales then had to be transformed into a single function value. Next, this function value was related to the physical time continuum so that a single time value resulted. CPT Shaw accomplished these tasks using the Generalized Value System which was developed by Professor Arthur Schoenstadt at the Naval Postgraduate School. He also relied heavily on techniques developed by Professor Glen Lindsay of the Naval Postgraduate School [ref 2]. Basically, these techniques first transformed subjective evaluations into an interval scale and subsequently into a ratio scale. Then the ratio scale data of the tactical variable is translated into a physical, time scale. Finally, CPT Shaw adds the two time scales together to obtain a single result. Standard optimization techniques are then used to optimize the network. His procedure for accomplishing this complex task will be discussed in a subsequent section.

2. The Variables

First, CPT Shaw identified the key variables that he considered crucial to the decision making process [ref 1:p.13-14]. The variables he identified included the following:

- Mission
- Time Available
- Equipment and Resources
- Threat Equipment and Capability
- Threat Mission
- Range to the threat
- Cover
- Concealment
- Environment

- Area of Operation or Theater
- Speed or vehicular Agility
- Distance to the Objective
- Obstacles
- Artillery

The next step was to analyze these variables to determine which variables could be fixed for a given scenario. These variables could then be eliminated from consideration as long as that scenario remained fixed. Mission, threat mission, area of operations, equipment and resources available, threat equipment and capability were eliminated using this technique [ref 1: p.14].

CPT Shaw then combined a number of variables into a new variable he introduced: line of sight (LOS). This LOS variable was defined as the number of enemy weapon systems that could observe a friendly weapon system at a given point. The variables that directly mapped onto this new variable included cover, concealment, environment, and range [ref 1: p14]. He felt that it was the combination of these variables and their corresponding effect on enemy observation that influenced route selection. LOS could be easily calculated using any of a number of standard, existing algorithms [ref 4]. Thus, these four variables were eliminated and LOS was added.

This techniques was also used to map three other variables into a new variable: localized speed. The effects of obstacles, environment, and vehicle speed combined to result in localized speed. Localized speed at a given point is what is crucial to the decision making process [ref 1: p14].

Two of the remaining variables were either transformed or eliminated. Range to threat was transformed into relative effective range (RER) to the greatest known threat. RER is a complicated concept that was developed by Seth Bonder and Bob Farrell. Basically, it gives the analyst the capability to compare different threat capabilities at different ranges. RER is discussed in detail in CPT Shaw's thesis [ref 1: pp 25-30]. Artillery was eliminated because its impact on movement decision making is primarily limited to minefields and obscurants which fall under environment [ref 1: p 14]. Thus, two variables, range to threat and artillery, are eliminated and a new variable, RER is introduced.

This process results in four key variables as long as the scenario remains fixed:

- Time
- Localized speed
- Relative effective range (RER)
- Number of lines of sight (LOS)

Finally, the variable, time, is fixed by the user of the algorithm. The user must determine how much time he is willing to lose in order to avoid major engagement with the enemy.

3. The Survey

Next, CPT Shaw surveyed a population of Army and Marine officers at the Naval Postgraduate School to determine what these officers felt was the relative importance of the remaining variables on tactical movement potential (TMP). He surveyed forty two officers and used multiple regression techniques to determine equations for TMP. The survey used five categories to rate the tactical movement potential of various combinations of LOS, RER, and localized speed [ref 1 pp.43 -60 and p.14]. He used TMP to mean anti-potential, which meant a large TMP reflected a poor position. He found two equations satisfactory, one with four variables and the other with five variables [ref 1: p.21]. The four variable equation was:

$$TMP = 118.24 - 0.15(RNG) + 12.\ (LOS) - 2.\ (SPD) + 0.2(LOS \times SPD)$$

4. Relating the Physical and Cognitive Scales

The final step of the procedure was to relate the two scales, the physical scale obtained from CAMMS and the cognitive scale derived from the TMP regression. The cognitive scale was transformed into a physical time scale. As stated previously, CPT Shaw relied on techniques developed by Professor Glen Lindsay to accomplish this task.

After translating the subjective data into an interval scale, CPT Shaw first determined the minimum and maximum values of TMP. These are the extreme points of the cognitive or interval scale. Fortunately, the survey only identified two extreme points, one best and one worst case combination. He used these values to convert the interval scale into a ratio scale [ref 2: pp.6-18]. Then he translated the TMP scale into a time scale. The lowest value of the TMP became the origin for the transformation onto the physical time scale. This point corresponded to adding zero additional time units to the physical scale. The maximum value (worst position) or opposite end of the scale was also obtained. Next, the user or a selected population was surveyed to determine just how much time they would spend to avoid the worst possible combination of state variables. This surveyed time value will subsequently be called the avoidance time. Then , a (0,1) TMP scale was obtained by dividing the TMP for a cell by the maximum TMP. This scaled TMP value was then multiplied through by the given avoidance time value for the worst possible combination resulting in a translated avoidance time scale. The scaled cognitive value of "avoidance time units" is then added to the time value required by the physical scale [ref. 1:pp 21-22]. For example, assume that the TMP range was from 5 to 15, and that the officer was willing to spend 5 minutes to avoid the worst (15) cell. Then, 5 minutes would be added to the traversal time of the 15 TMP cell, 2.5 minutes would be added to the traversal time of the 10 TMP cell and 0 minutes would be added to the traversal time of the 5 TMP cell. The procedure used by CPT Shaw results in a single time value for optimization purposes [ref 1: pp 21-22].

CPT Shaw states this procedure only works if the maximum and minimum anchor values for TMP can be easily identified. If these values cannot be obtained then the transformation of the cognitive scale onto the physical time scale cannot be performed.

5. The Optimization

Since the rational minimum and maximum TMP values and the single time scale had been determined, CPT Shaw solved the problem as a shortest path problem with the single time value as the path length. He used Dijkstra's algorithm which is a label setting search algorithm [ref 6: pp. 203-209]. The algorithm simply performs its search on the translated single time that resulted from the combination of the tactical and physical traversal times.

The problem can also be solved another way without resorting to the single time scale technique. CPT Shaw discussed this procedure in his thesis, but he did not use this procedure. In tl case, an optimization involving the two variables, TMP and traversal time, is performed. TMP must be minimized with the added constraint that the path cannot exceed a maximum allotted time. A standard technique to perform this optimization is available. This technique is known as Lagrangian relaxation. Briefly, a Lagrangian multiplier is used and the objective function becomes:

min [(TMP + LAMBDA x T) x X - LAMBDA x TMAX]

where:

X is a vector of arcs which make up the network solution.

T is the physical travel time associated with each arc.

TMAX is the maximum travel time to traverse the network.

The problem is to solve for an appropriate value of LAMBDA between 0 and LAMBDAmax (the maximum traversal time multiplied by the number of vertices). The interval between LAMBDAmin and LAMBDAmax is then narrowed until the appropriate value is obtained [ref 1: pp.34-35].

C. PRELIMINARY ANALYSIS OF THE SHAW PROCEDURE

1. Determing TMP and Traversal Time

The eleven variables used to compute TMP seem comprehensive in most respects. By doctrine, the Army officer considers METT - mission, enemy, troops and time when he selects a route. CPT Shaw considered all of these ideas in his eleven variables. However, it is important to note that many of these variables are "fixed" by the scenario. Therefore the TMP function derived from the officer survey is only valid as long as those variables remain fixed. This fact requires that a number of TMP functions must be developed to cover each combination of the fixed variables. In addition, the CAMMS model is an excellent selection to provide environmental data and calculate traversal times. This part of the methodology is well founded.

2. The Single Time Solution Technique

The single time solution technique used in the final step of CPT Shaw's procedure which combines TMP and traversal time into a single value was discussed with Professors Parry and Lindsay of the Naval Postgraduate School. After the consultation, the author concluded that the technique has some limitations. First, CPT Shaw assumed that the avoidance time function is linear between the maximum and the minimum values as he only obtained from the user the avoidance time for the worst case TMP and he assigned a value of 0 to the best case TMP. The true user avoidance time function for values between these points may not be linear. The user avoidance function must be determined by surveying the user over a larger number of the remaining state variables. However, even if this function was obtained the avoidance time and traversal time scales could not be added. Adding these values, avoidance time (a function of TMP), and traversal time is actually a hueristic weighting technique and not a true optimal solution technique. Thus, the Lagrangian relaxation technique which determines the best TMP route for the available time should be considered.

Another potential problem with combining TMP and traversal time onto a single scale is that they are not independent. The TMP value is a function of LOS, speed, and RER. The traversal time is a function of speed. Thus, the two values, TMP and traversal time are both functions of speed. When the variables in the TMP function are weighted with the avoidance time, you obviously do not change the traversal speed. However, the relative importance of speed is changed in the overall optimization. The TMP speed (as well as the other TMP variables in the multiple regression) is multiplied by a constant (Avoidance Time/TMPmax) in order to transform TMP into the physical scale. This value is then added to the traversal time, a pure function of the traversal speed. The effect on the optimization may be that the true importance of speed could be changed. Perhaps, only certain avoidance time ranges might be effective due to changes in the relative importance of speed. In any case, this effect is another argument for the Lagrangian relaxation technique.

A final potential problem with the single time solution technique is the human factor. One could expect large differences between the avoidance times (for the worst possible TMP cell) and the traversal times. For example, if the avoidance time for a worst cell (which the user inputs into the model) was 200 minutes, the actual movement time may take much less than 200 minutes. This was shown by examining the route in Janus(A) and in the CAMMS speed map feature. The difference between the times in itself is not surprising and is wholly consistent with the model. The cell traversal times and not the single, combined time value determine the complete route traversal time. In other words, the tactical time units that are added for optimization purposes do not affect the actual traversal time. The actual traversal time remains a function of the physical effects of the environment. However, the difference between the times will confuse the typical Army user who will approach the problem with the idea of selecting the best route for a given traversal time. He will probably interpret the avoidance time as the network traversal time. The Army officer would better understand the Lagrangian relaxation solution where the best route for the available time is obtained.

This human problem could also be lessened if the CAMMS/Shaw model displayed the expected traversal time of the network. The user would then know how much time he would probably spend crossing the terrain network. If he had more actual time than predicted by the model, he could then select a higher avoidance time.

3. Defining the Area of Operation

Another problem with the algorithm involves selecting the area of operation. When a new area of operations is selected, the Dijkstra search fails and an error message is given approximately 90 percent of the time. However, if one repeatedly inputs the area of operation, the search will eventually function successfully. The problem is probably occurring due to the network crossing the boundary of the area of operations. This problem could be solved by preprocessing the edges that cross the boundary and assigning them an extremely large value. The Dijkstra search would then avoid these edges. The problem could also stem from an error in the model's code. In any case, the problem needs to be corrected.

4. Sensitivity Analysis

The CAMMS/Shaw model was used to select routes in two areas of operation under the scenarios described in Chapter

III and Appendix B. Time was varied from 0 minutes to 360 minutes to avoid the worst cell in ten minute increments. Where large variations occurred in this ten minute interval the time value was varied every minute. The behavior of the model for several avoidance times is recorded in Figures 1 to 12 of Appendix D.

The model never reaches one recommended route as it oscillates from routes on the left side to routes on the right side of the area of operation. Even at avoidance times well over 100 minutes for a 4000 meter movement, the model selects routes that differ dramatically. Often, these routes are only slightly different than routes it had selected earlier. This oscillation does not imply that the algorithm is functioning improperly. The avoidance time affects every cell in the network by weighting the TMP factor more heavily. Thus, radical shifts are possible and even likely. However, these shifts could serve to confuse users on the meaning and effectiveness of these routes.

III. DESIGN OF THE EXPERIMENT

A. GENERAL

The design of the experiment must remain focussed on two things: the purpose of the thesis and the capabilities of the Shaw and Janus(A) models. All design decisions are based on these two points.

B. THE SIZE OF THE RESPECTIVE FORCES

Before the scenario can be developed, the size of the respective forces must be decided. The key factor in determining both force sizes is the attacking force. This is because the defender to attacker ratio is normally three to one by Army doctrine. So the question becomes how large should the attacking force be?

The attacking force is the force that will follow the routes prescribed by the officers and CPT Shaw's model. Since the officers can select routes for units of any size, CPT Shaw's model becomes the determining factor in selecting the size of the attacking force. CPT Shaw developed his model to select a route for a single vehicle or a small unit. This single route would then be used to model the movement of the entire unit. Because larger units often move over multiple routes, the smallest possible attacking force should be selected.

Two attacking force sizes were considered: a platoon, with four weapon systems, and a company, with 14 weapon systems. The company normally consists of three platoons and a company headquarters. One advantage of a platoon sized force is that a platoon nearly always moves along one route. Companies on the other hand sometimes use multiple routes to deploy their platoons to the objective.

The platoon sized force was not selected for two reasons. The first reason is the purpose of this thesis. Independent platoon scenarios in raids or rear battle situations or even some deliberate attacks could be developed. However, these limited scenarios would not reflect most offensive scenarios. As a result, analysis based on these limited scenarios would have little relevance to the vast majority of offensive operations. Therefore, the questions regarding the appropriateness of the model to the Army as a whole could not be addressed. The second reason is that a platoon rarely moves along a separate route independent of the other platoons in the company. Thus, the platoon route would be influenced by the dispositions of friendly forces. The dispositions of friendly forces are not considered in CPT Shaw's model. These facts make a platoon force inappropriate for consideration.

The company sized force was selected because it is the smallest force that normally operates independently of the rest of the force inside its area of operation. Independence does not mean that the company is not integrated into the battle plan by its higher headquarters. The company's area of operation and objective are assigned by its higher headquarters. However, inside that assigned area of operations the company is free to maneuver to its objective as it chooses. Since a company attacking force was selected, the size of the defending force was also fixed by the three to one rule. A platoon consisting of four weapon systems would be the defense.

Two assumptions about the company's movement have to be made. First, the company movement is restricted to one route. Second, it must move over that route in a prescribed formation.

C. THE PLACE OF THE BATTLE

The Lauterbach area of West Germany was selected as the place of the battle for three reasons. First, the CAMMS/Shaw model located at TRAC - Monterey only has a terrain base built for the Lauterbach area. Terrain Data for another area would have to be imported. Also, the multiple regression equation for the TMP value obtained from the officer survey was based on the Lauterbach area. This equation may not apply to other areas. Finally, the Lauterbach area is suitable because it is an area in West Germany that figures prominently in many Army scenarios.

D. THE POSITION OF THE FORCES

Selection of the defensive positions was made using a map reconnaissance and the Janus(A) model. The map reconnaissance was made to generally select a number of appropriate defensive areas of operation. Then, the Janus(A) model was used to make the final selection because of the LOS feature of the model which allows the model user to graphically determine what a weapon system can see at a given point on the battlefield. This feature of Janus(A) is critical to position selection because positions with a poor LOS in the Janus(A) model would not be able to observe the approaching enemy. Thus, the defenders would not be able to engage the enemy over most of the area of operation. As a result, there would be few casualties generated and very little difference between the routes. After careful study, two positions were finally selected. The positions selected are shown on overlays in Appendix B. Two positions were selected so that results in different environments could be examined. A larger number was not feasible due to time constraints.

Position one is located at the military crest of a small hill overlooking a town and a large open area. This position is quite dominating as it has LOS over a good portion of the area of operations. This position will defend an attack from the assembly area to the east as shown in overlay one.

Position two is located just below the military crest of a large hill overlooking a city and a wooded area. This position has LOS over a more limited amount of the area of operations. Thus, there is more dead space for weapon system movement in this area of operation. This position will defend an attack from the south. Company assembly areas for the attacking force were selected just outside of the range of the defenders' direct fire weapons, approximately 4500 meters from the objective.

Great care was taken so that the precise locations of the individual weapon system's defensive positions in the Janus(A) model, the CAMMS/Shaw model, and the officer survey were the same.

E. THE SCENARIO

The tactical scenario is also enclosed in Appendix B. The general enemy and friendly situation is similar to the situation used in CPT Shaw's survey so that the TMP multiple regression equation would apply. The same general situation applies to each area of operations. The unit mission is a deliberate attack from a company assembly area to a prepared defensive position. Each of the officer respondents and the CAMMS/Shaw model were required to select routes from the company assembly to the objective under different time scenarios in each of the two areas of operation.

The time conditions are that they should move to the objective:

- as fast as possible

- while spending up to 30 minutes in order to avoid major conflict before the objective
- without regard to time (best route).

Since this task must be accomplished for each of the two areas of operation, this means that six routes must be selected by each respondent.

F. OFFICER ROUTES

Officer routes were obtained by individually surveying selected officers "in person". The "in person" survey technique was used because time tests demonstrated that the survey required nearly an hour to complete. This time was greatly reduced by developing map boards with the overlays already attached to them and briefing the officer. This technique reduced the time required for the respondent to complete the survey to approximately fifteen minutes. Ten officers selected from a class at the Naval Postgraduate School were chosen to complete the survey. The prime limiting factor on the number of officers was time using Janus(A) as each of these officers was selecting six routes and each route required thirty replications of a scenario using this model.

G. CAMMS/SHAW ROUTES

In addition, six routes were selected from the sensitivity analysis that was performed on the CAMMS/Shaw model. The 0,30, and maximum minute avoidance time routes were selected so that these routes could be compared to the officer selections. Three other routes were also selected based on the type of approach selected so that different approaches could be examined. For example, if a left side approach was already selected then a right side approach was selected. This selection method was used because of the limited number of routes that could be run in the Janus(A) model. Different approach routes would provide greater insight into the CAMMS/Shaw model performance than routes that were nearly the same.

H. THE JANUS(A) MODEL

The next step was to build the appropriate scenario in the Janus(A) model. The procedure for building this scenario is discussed in detail in Appendix A.

The routes obtained from the officers and the CAMMS model were then input into Janus(A). The routes are input by selecting a number of movement nodes to model piecewise linear sections of the route. The weapon systems then move in a straight line from node to node until they have completed their route. When the friendly weapon system reaches the attack position at the base of the objective (approximately 200 meters away from threat weapon systems), the battle is terminated. This termination condition was chosen because the study is not interested in the results of these extremely close engagements, but rather the impact of the route. Each of these routes were run systemically thirty times on the Janus(A) model. This replication was necessary to determine the variance and distribution of the casualty figures due to the Janus(A) model's stochastic nature.

I. FORMATIONS

A final step was to choose the formation that the attacker would use on his route. Three formations were considered:

- an individual weapon system column formation where the weapon systems would move in a column formation throughout the route.

- the Janus(A) default unit formation where units move in a column formation until they acquire the enemy. Then the weapon systems move on-line to fire [ref 7: pp 12-14].

- an on-line formation where the weapon systems moved on line in a very tight formation throughout the route.

The different formations were tested in the Janus(A) model on some of the base case scenarios. Different results were obtained with each of the different formations. The Janus(A) unit default formation was chosen for two reasons. First, this formation gave the unit the ability to move on line when it engaged the enemy. Also, this formation's model run time was much quicker than the other formations model run time. Speed was important because of the large number of model runs required.

J. DATA COLLECTION AND REDUCTION

After each run red and blue casualty figures at each of five range breaks were recorded. The range breaks (in meters) were:

- 0 to 1000
- 1000 to 1500
- 1500 to 2000
- 2000 to 2500
- beyond 2500

The data had to be manually down loaded from the Janus(A) model due to hardware problems that resulted from an upgrade of the system at TRAC-Monterey. The database was then transferred into mainframe files where it could be analyzed using GRAFSTAT.

K. SUMMARY

The following table summarizes the experiment using Janus(A):

	NUMBER OF SUBJECTS	ROUTES PER SUBJECT	RUNS PER ROUTE	TOTAL RUNS
OFFICERS	10	6	30	2160
CAMMS/ SHAW	1	12	30	360
TYPE OF FORMATION	3	5	30	450
TOTAL				2970

The simulation results of the CAMMS/Shaw routes at the different avoidance times were compared to determine if routes with larger avoidance times are more effective. This would help to answer the second thesis question: Are better routes in the decision aid truly better? The simulation results of the CAMMS/Shaw routes and the officers were also compared to determine how CAMMS performs in relation to active duty officers.

IV. ANALYSIS OF EXPERIMENTAL RESULTS

A. MEASURE OF EFFECTIVENESS (MOE)

The number of blue kills was chosen as the measure of effectiveness for this study. This is a direct measure of the survivability of the route. The possible range of this MOE is from 0 to 14, as the blue company consisted of 14 weapon systems. Obviously, if no blue weapon systems were destroyed, the route was very effective (survivable). Conversely, if 14 vehicles were destroyed, the route was poor.

The number of red kills was not chosen as an MOE because of the insignificant number of red killed in the simulation. Nearly 80 percent of the routes resulted in no red kills in the 30 model runs. The other routes resulted in between 0 and 0.23 kills per run. This low number of kills probably occurred because red systems were in hull-defilade positions. Thus, blue systems rarely detected, observed, or fired at them. The low number of red kills was insignificant in comparison to the number of blue kills (see Appendix C).

The number of blue kills was examined over two range intervals. The first interval was the entire route. The data for the entire route were examined because they obviously evaluate the entire route. The second interval was the route up to a point 1000 meters from the nearest red system. The second interval was chosen because units often begin deploying their platoons on-line and begin fighting the close-in battle at this point. While deploying on-line and into assault positions , units often deviate from the one prescribed route, thus violating a key assumption. This violation could make evaluation of data in the last range band (0 to 1000 meters) suspect. Differences in the measure of effectiveness between the routes are evaluated using nonparametric techniques. Nonparametric techniques are used because the normality assumption required for standard ANOVA is violated. Specifically, the Kruskal-Wallis test of equal medians is used to evaluate differences. This test does not assume a normal blue killed distribution. This test is discussed in detail in *Nonparametric Methods of Quantative Analysis* by Gibbons [ref 8: pp 173-181].

The reader should note that the "blue killed" axis on all graphical portrayals of the MOE ranges from 0 (the minimum) to 14 (the maximum) on all figures, which facilitates direct comparison between different figures.

B. COMPARING MODEL GENERATED ROUTES

1. Entire Route

Figures 1 and 2 show box plots of the CAMMS/Shaw results for the complete route in the north-south and east-west attacks, respectively. These results and all other results are tabulated in Appendix C. In both attacks the number of blue casualties initially decreases as one would expect if the CAMMS/Shaw model was completely consistent. However, in the east-west attack blue casualty figures for routes with avoidance times of 90, 200, and 300 minutes are higher than earlier routes. These casualty figures are statistically different at p-values much less than 0.01. Also, in the north-south attack the means of the casualty distributions for routes with avoidance times of 200 and 300 minutes are statistically less effective than routes with earlier avoidance times at p-values of less than 0.0001 (200) and 0.01 (300). Thus, this study found an inconsistency when comparing the complete CAMMS/Shaw routes with certain avoidance times against each other.

2. Route Up To 1000 Meters

Figures 3 and 4 show the results of the CAMMS/Shaw route up to the 1000 meter mark. Once again, although the casualty figures initially decrease, routes at greater avoidance time values yield casualty distributions that are statistically worse than routes for earlier time values. In the north-south attack the lowest casualty distributions occur at routes with avoidance times of 30 and 60 minutes. Indeed, the 30 minute avoidance time routes never experiences a single blue casualty up to the 1000 meter mark. However, the casualty distributions for routes with avoidance times of

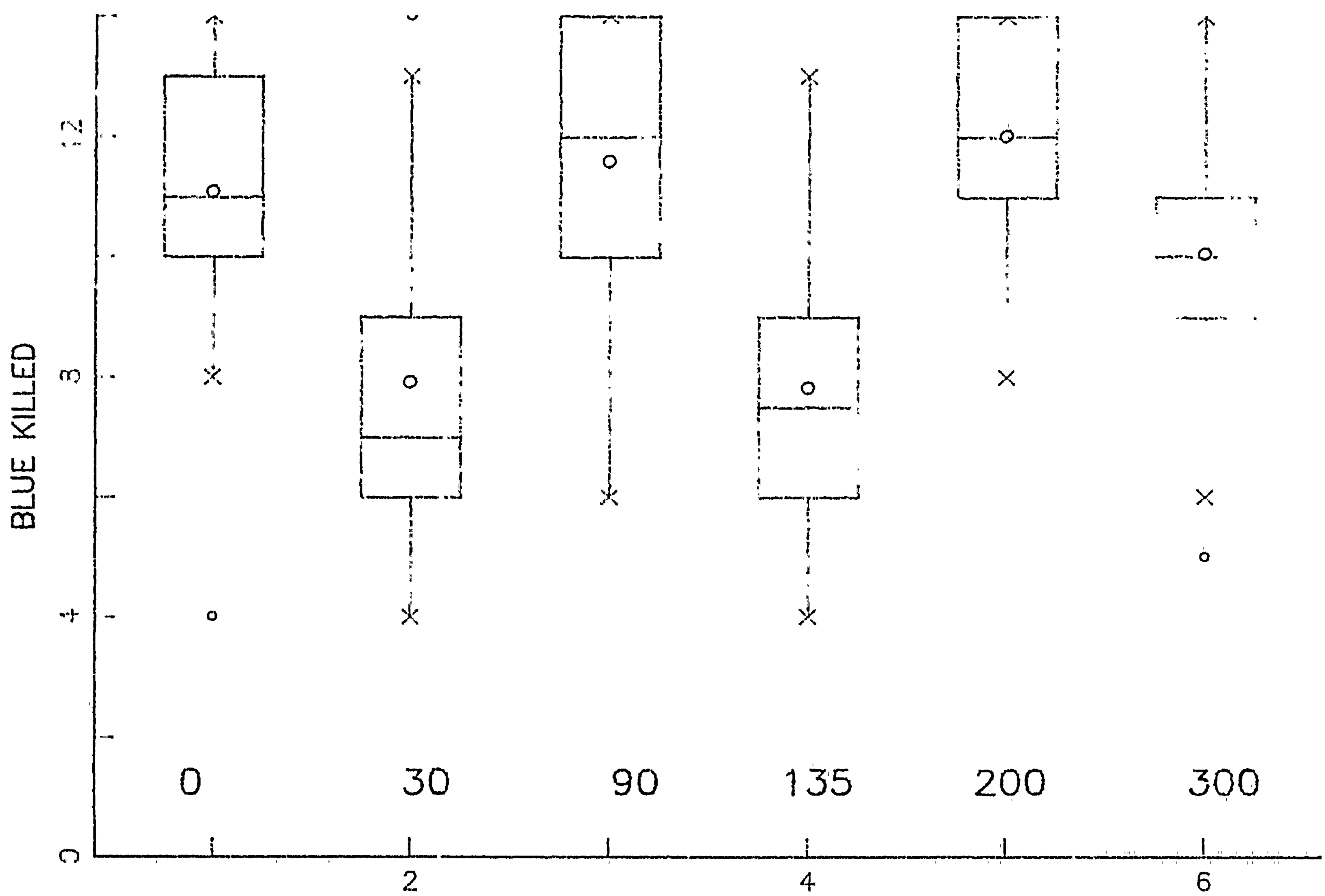
200, 300 and 330 minutes are statistically less effective than the 30 minute route with p values below 0.001.

3. Traversal Times

The traversal times of the different CAMMS/Shaw routes are depicted in Figure 5. These traversal times were determined in the base case scenario. The traversal times cannot be determined in systemic Janus(A). Thus, only one value is plotted for each avoidance time. If the CAMMS/Shaw and the Janus models were completely compatible and accurate, travel time would never decrease as avoidance time increases. However, the chart shows that this relationship does not exist. Several routes with higher avoidance times take less time than earlier routes.

CAMMS/SHAW RESULTS FOR THE COMPLETE ROUTE

EAST--WEST ATTACK



AVOIDANCE TIMES

Figure 1

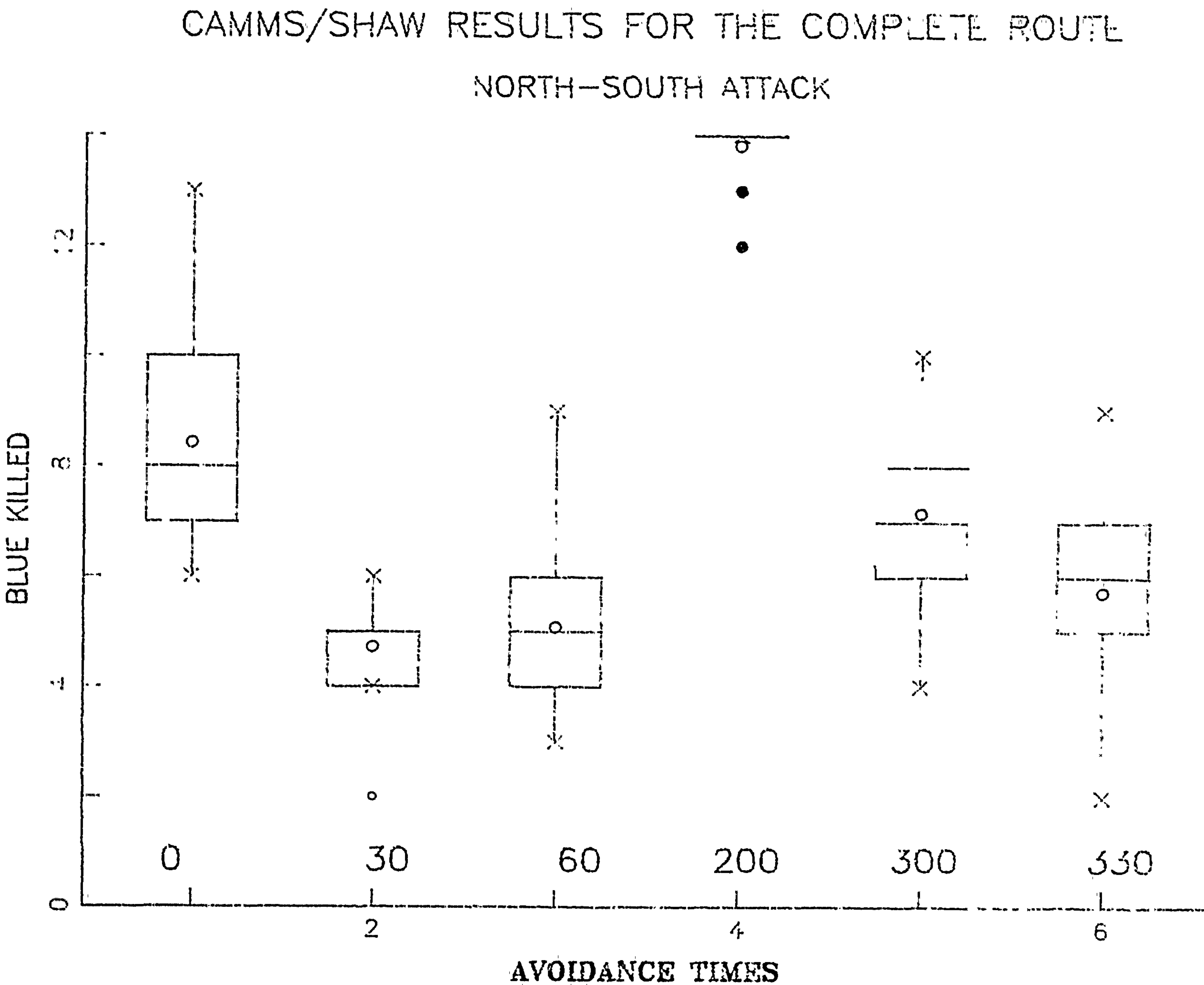
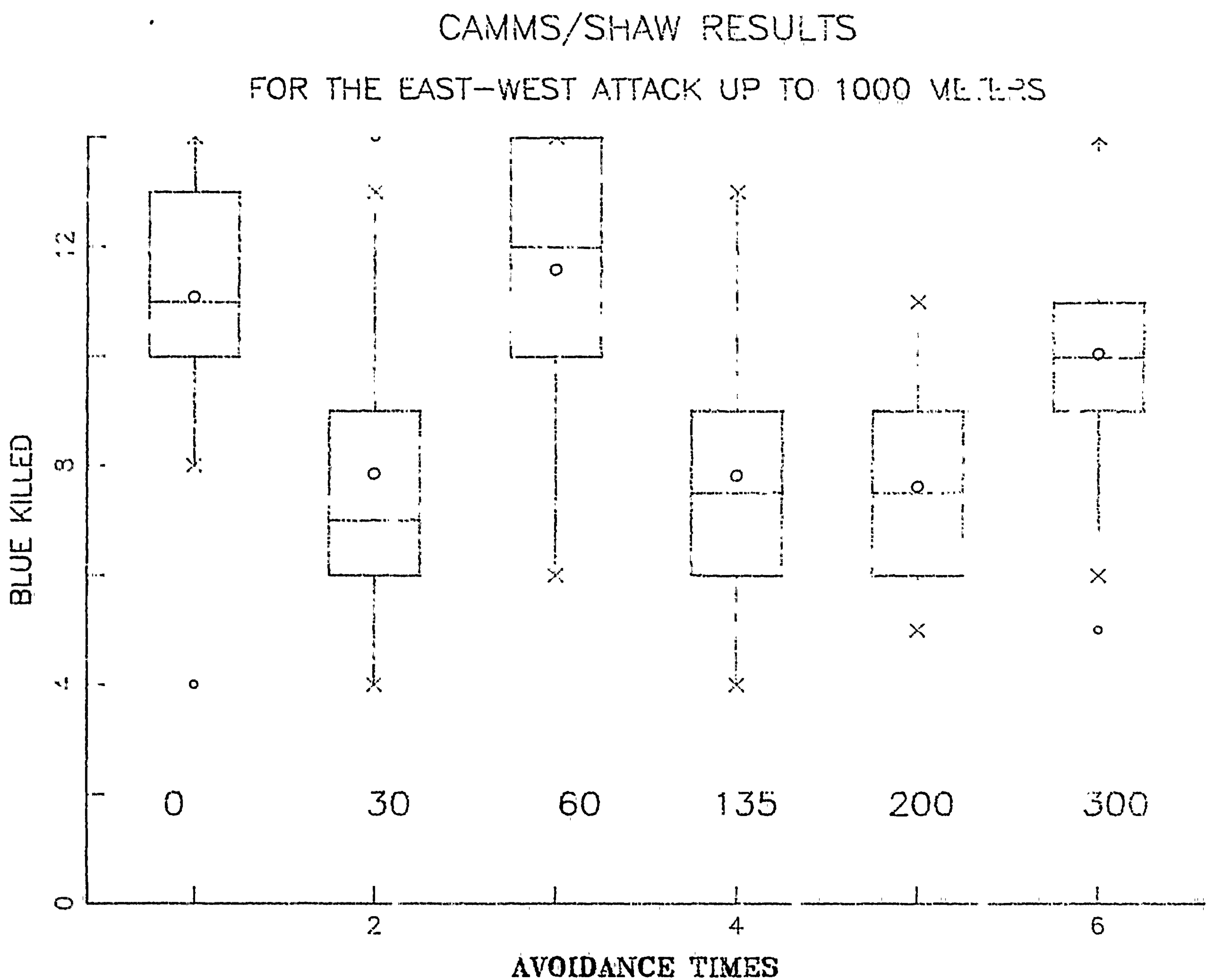

CAMMS/SHAW RESULTS FOR THE COMPLETE ROUTE
NORTH—SOUTH ATTACK
BLUE KILLED
0
4
8
12
0
30
60
200
300
330
2
4
6
AVOIDANCE TIMES

Figure 2

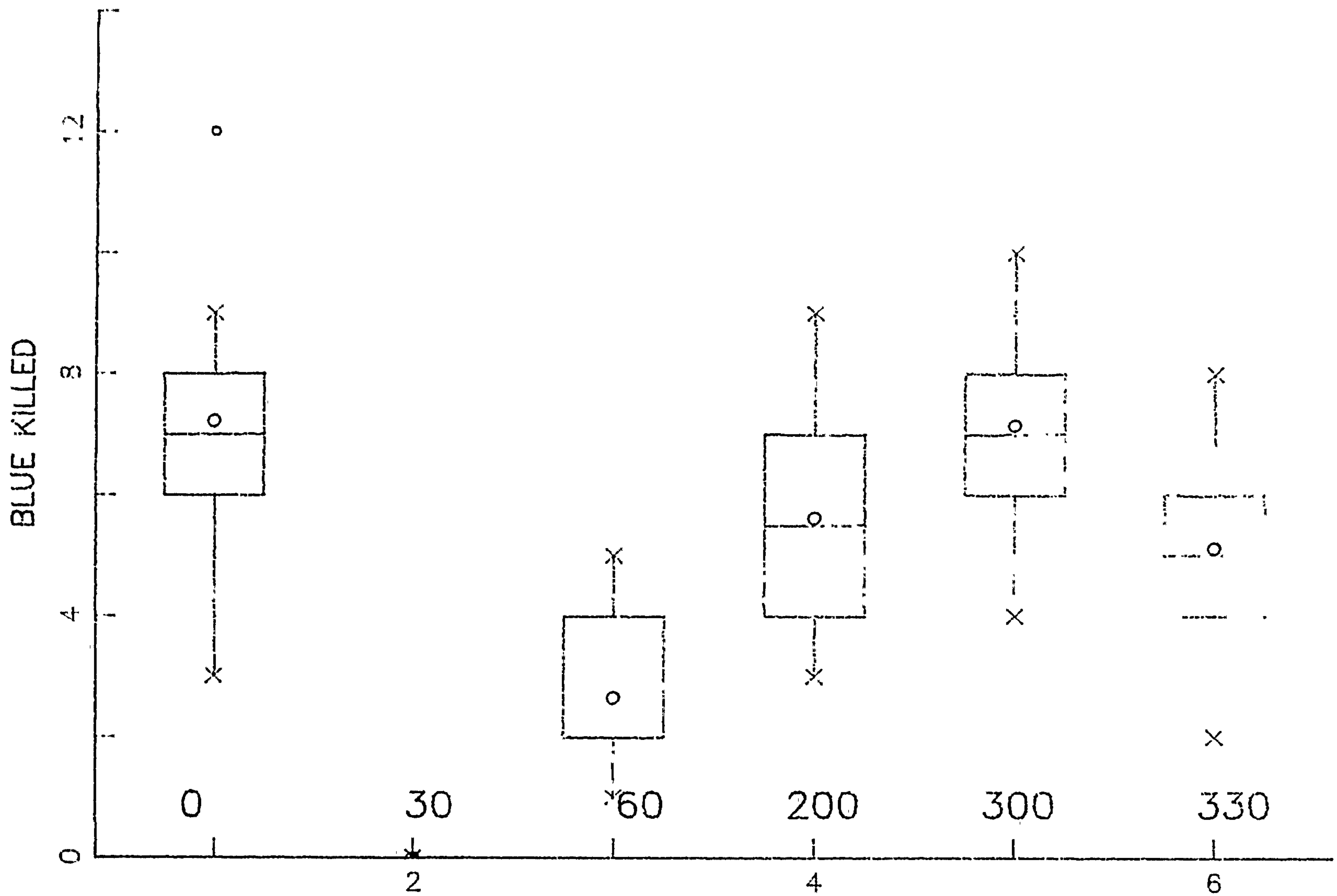


CAMMS/SHAW RESULTS
FOR THE EAST-WEST ATTACK UP TO 1000 METERS
BLUE KILLED
12
8
4
0
0
30
60
135
200
300
2
4
6
AVOIDANCE TIMES

FIGURE 3

CAMMS/SHAW RESULTS

FOR THE NORTH-SOUTH ATTACK UP TO 1000 METERS



AVOIDANCE TIMES

Figure 4

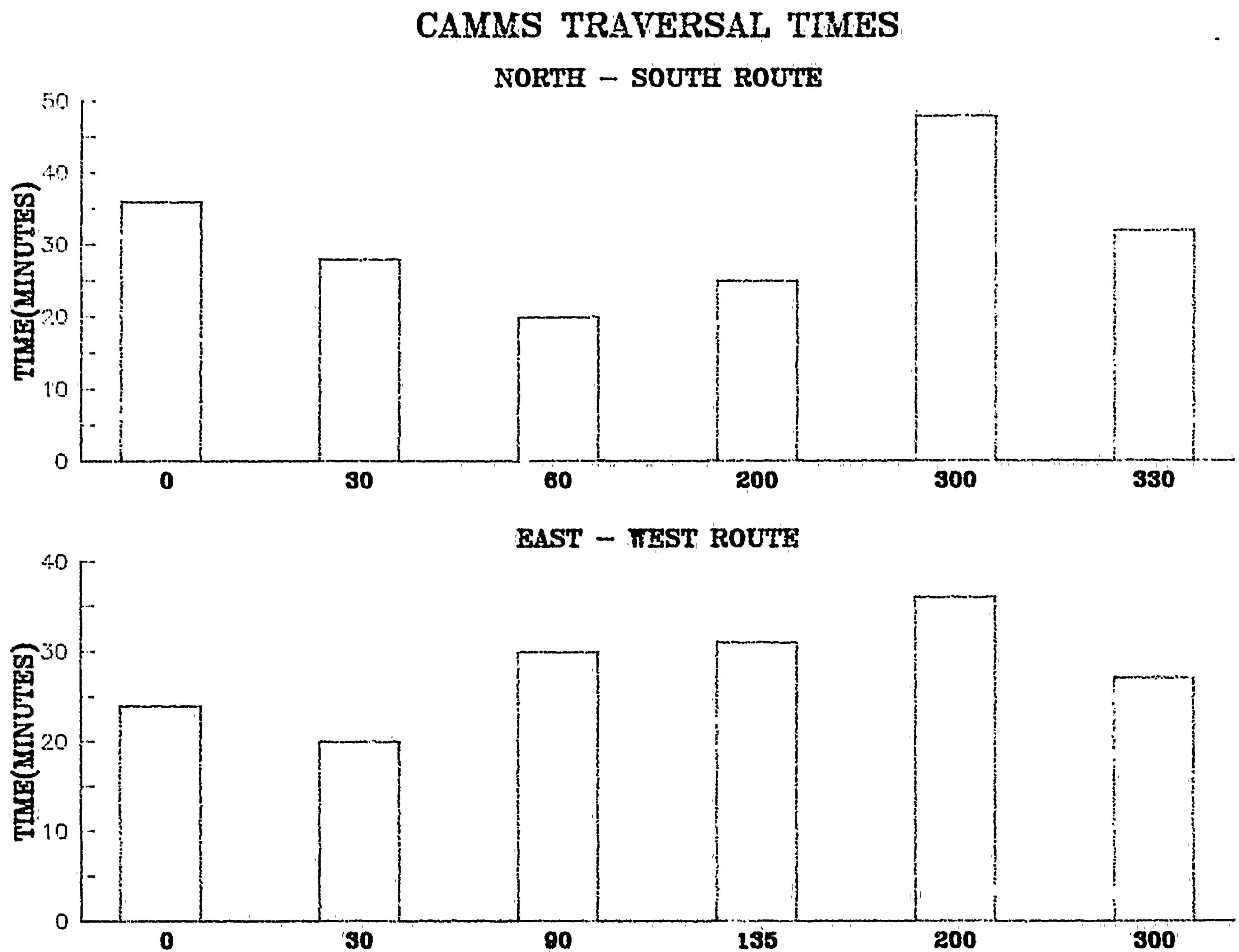

CAMMS TRAVERSAL TIMES
NORTH – SOUTH ROUTE
TIME(MINUTES)
50
40
30
20
10
0
0
30
60
200
300
330
EAST – WEST ROUTE
TIME(MINUTES)
40
30
20
10
0
0
30
90
135
200
300

FIGURE 5

4. Analysis

The inconsistent traversal time result is not surprising due to the fact that Janus(A) does not possess the detailed terrain data that is present in the CAMMS/Shaw model [ref 1:pp 7-8 and ref 10]. Therefore, it would only be a chance occurrence if the travel time always increased as avoidance time increased. This is especially true since the traversal time range difference in both scenarios is only 16 minutes. Only the 300 minute avoidance time route in the north-south scenario, which travels completely around the defensive position, is outside of this range. However, Janus(A) is not designed to predict traversal times. This is the function of a mobility model such as CAMMS. Therefore, this result alone does not invalidate the analysis.

This study also found that some routes that were judged as better by the CAMMS/Shaw model were judged as less effective by Janus(A). Janus(A), as an Army Models Board approved high resolution combat model, is designed to predict the battle calculus of combat. Therefore, this result is more troublesome because it means that the CAMMS/Shaw model is somewhat inconsistent with respect to the battle calculus that Janus(A) is supposed to predict. However, before one can conclude that there are problems with the CAMMS/Shaw algorithm, the possible causes of the discrepancy must be examined.

The first cause could be differences in the terrain representations between the two models. As stated earlier the CAMMS/Shaw model has a much more detailed terrain representation than does the Janus(A) model. These differences between the terrain models could explain LOS and speed differences between the models. LOS and speed are two of the three variables in the TMP regression function so naturally these could affect TMP and cause the discrepancy. The terrain differences between the models were also pointed out by the differences in the traversal time predictions. The traversal times as evaluated by Janus(A) were different than the traversal times predicted by CAMMS.

A second possible cause is that the algorithms inside Janus(A) may not accurately simulate combat which means that Janus(A) is not effective enough as a combat model to evaluate the routes. This would result in inaccurate casualty figures which would invalidate all results.

Another cause may be that the TMP regression function is flawed in some way. If TMP were flawed, the result would be inaccurate evaluations of the TMP of the various cells. As a result, the route recommended by the CAMMS/Shaw model would be based upon inaccurate data. This problem could be addressed by performing another officer TMP survey with a different population. Any of these three possible causes or a combination of them could cause the problems that were discovered during this study.

A third cause could be that the avoidance time may be limited to certain range values. This result could possibly be due to the fact that both traversal time and TMP are functions of speed. Perhaps, the avoidance time might only be valid from 0 to less than 60 minutes, which would be consistent with the results achieved in this study, since avoidance time decreased initially in both scenarios. However, a much larger number of routes at various avoidance times would have to be evaluated to determine if a valid avoidance time range exists.

A final cause may be that the heuristic single time solution technique may not be accurate enough. If this were the case, then a different optimization, such as the Lagrangian relaxation would be required.

To attempt to determine which of the five possible causes actually resulted in the discrepancy is beyond the scope of this study. However, several studies could be undertaken to try to provide insight into this problem. Some of these studies are discussed in Chapter Five.

C. CAMMS/SHAW VS. ACTIVE DUTY OFFICERS

1. Entire Route

The complete route mean blue killed distributions for the 10 officers at the 3 avoidance times are shown in Figures 6 and 7. There are no statistical differences between the means of the three distributions in the north-south or the east-west attack at any reasonable p-value level.

In the north-south attack at 0, 30 and maximum minute avoidance times the officer mean blue kills were 9.2, 9.4 and 8.96, respectively. This compares with CAMMS/Shaw means of 8.1, 4.7 and 5.7 blue kills per run. CAMMS/Shaw routes are significantly better than the officer routes with p values of 0.07 (0), and less than 0.0001 for the 30 minute, and maximum avoidance time cases.

In east-west attack at avoidance times of 0, 30, and maximum minutes the officer mean blue kills were 6.21, 6.3, and 6.5 compared with CAMMS/Shaw means of 11.1, 7.9,and 10.2, respectively. The CAMMS/Shaw model routes are significantly less effective than the officer routes in the 0 minute and maximum avoidance times cases with p-values of less than 0.001. There is no significant difference at the 0.05 significance level between the 30 minute avoidance time routes. The p-value is 0.11.

2. The Route Up To 1000 Meters

The officer mean blue killed distributions at the different avoidance times for routes up to 1000 meters from the objective are depicted in Figures 8 and 9. Once again, there are no statistically significant differences between the effectiveness of the three officer routes at any reasonable level of significance.

In the east-west attack, the overall officer means for the 0,30, and maximum avoidance times are 5.96, 5.97, and 6.02, respectively. The CAMMS/Shaw means for 0,30, and maximum avoidance times are 11.1, 7.9, and 10.02 respectively. The CAMMS/Shaw route is significantly less effective than officer's routes at p-value levels of less than 0.0001 in the 0 and maximum minute cases and 0.04 in the thirty minute case.

In the north-south attack the overall officer means for the 0,30, and maximum minute avoidance time cases are 5.88, 6.16, and 4.84, respectively. The CAMMS/Shaw means were 7.2, 0, and 5.1. The CAMMS/Shaw model performed better significantly better than officers in the 30 minute case with a p-value of less than 0.0001. CAMMS/Shaw also performed better in the 0 minute case with a p-value of 0.10. There was no significant difference between the model and the officers in the maximum case at any reasonable significance level.

3. Traversal Times

The traversal times for the officers are depicted in Figure 10. There is no significant differences between the means of the distributions in the north-south or east-west routes. However, as stated earlier Janus(A) should not be used to predict travel time.

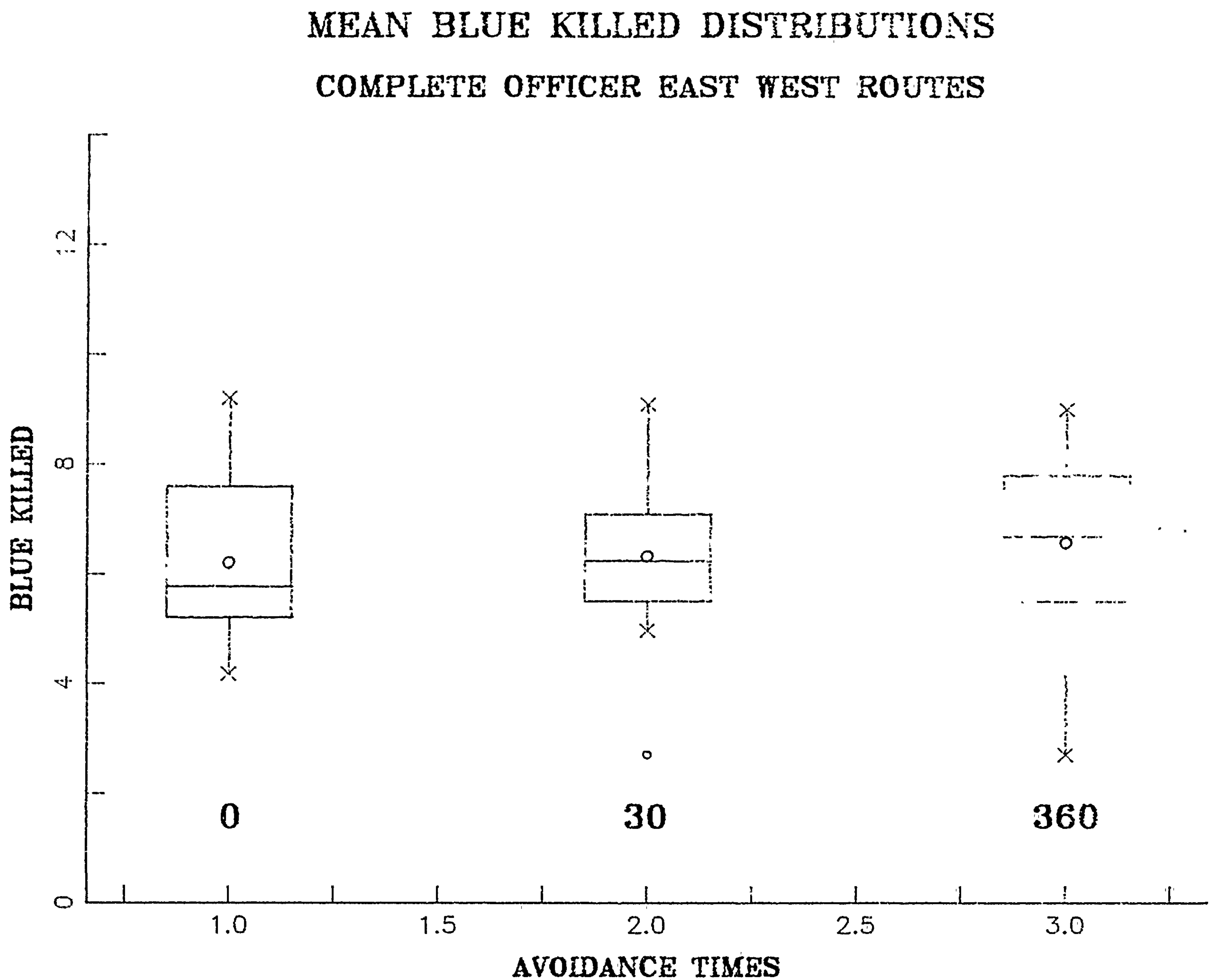

MEAN BLUE KILLED DISTRIBUTIONS
COMPLETE OFFICER EAST WEST ROUTES
BLUE KILLED
0
4
8
12
0
30
360
1.0
1.5
2.0
2.5
3.0
AVOIDANCE TIMES

Figure 6

MEAN BLUE KILLED DISTRIBUTIONS

COMPLETE OFFICER NORTH–SOUTH ROUTES

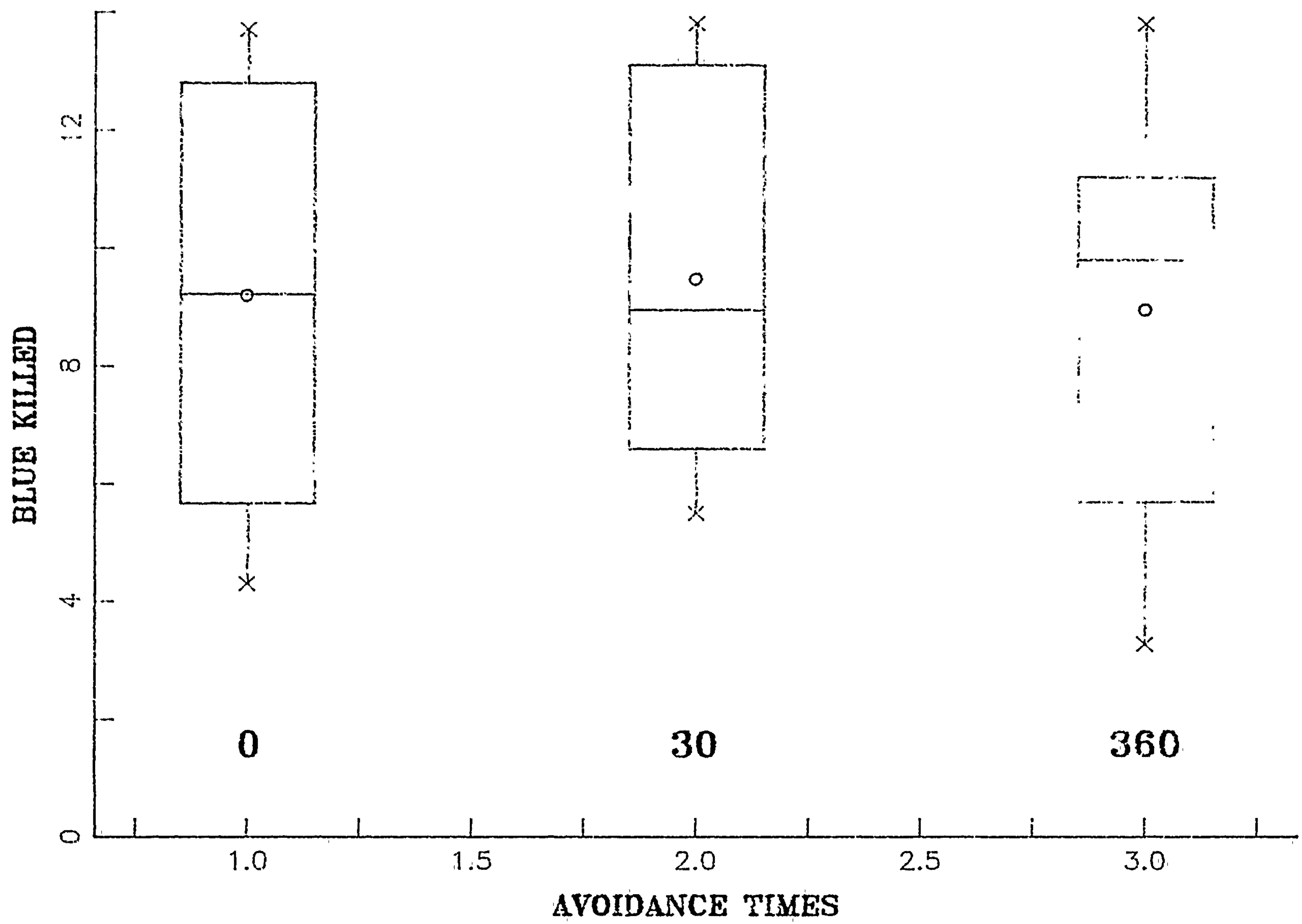


Figure 7

MEAN BLUE KILLED DISTRIBUTIONS

OFFICER EAST–WEST ROUTES UP TO 1000 METERS

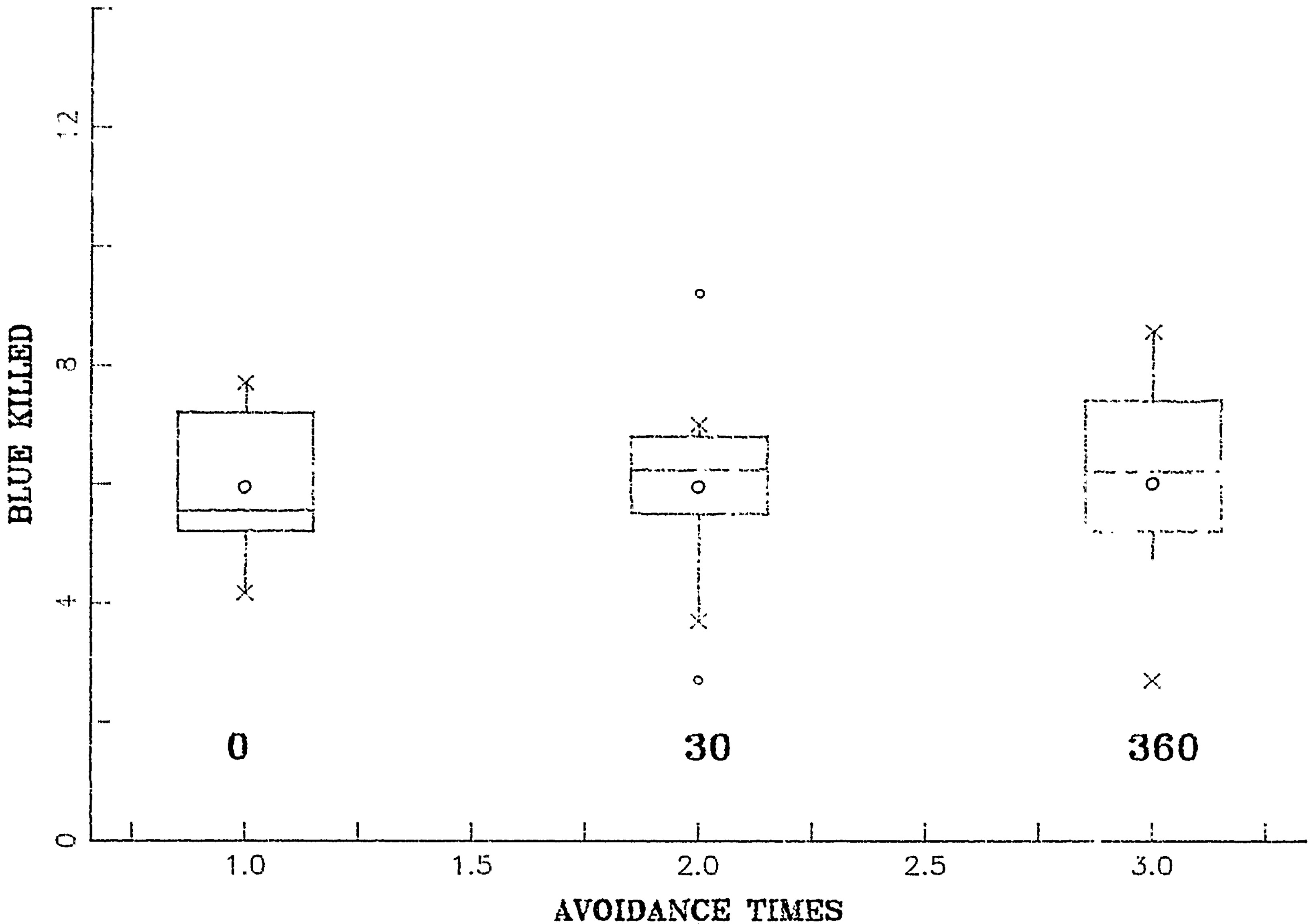


Figure 8

MEAN BLUE KILLED DISTRIBUTIONS

OFFICER NORTH-SOUTH ROUTES UP TO 1000 METERS

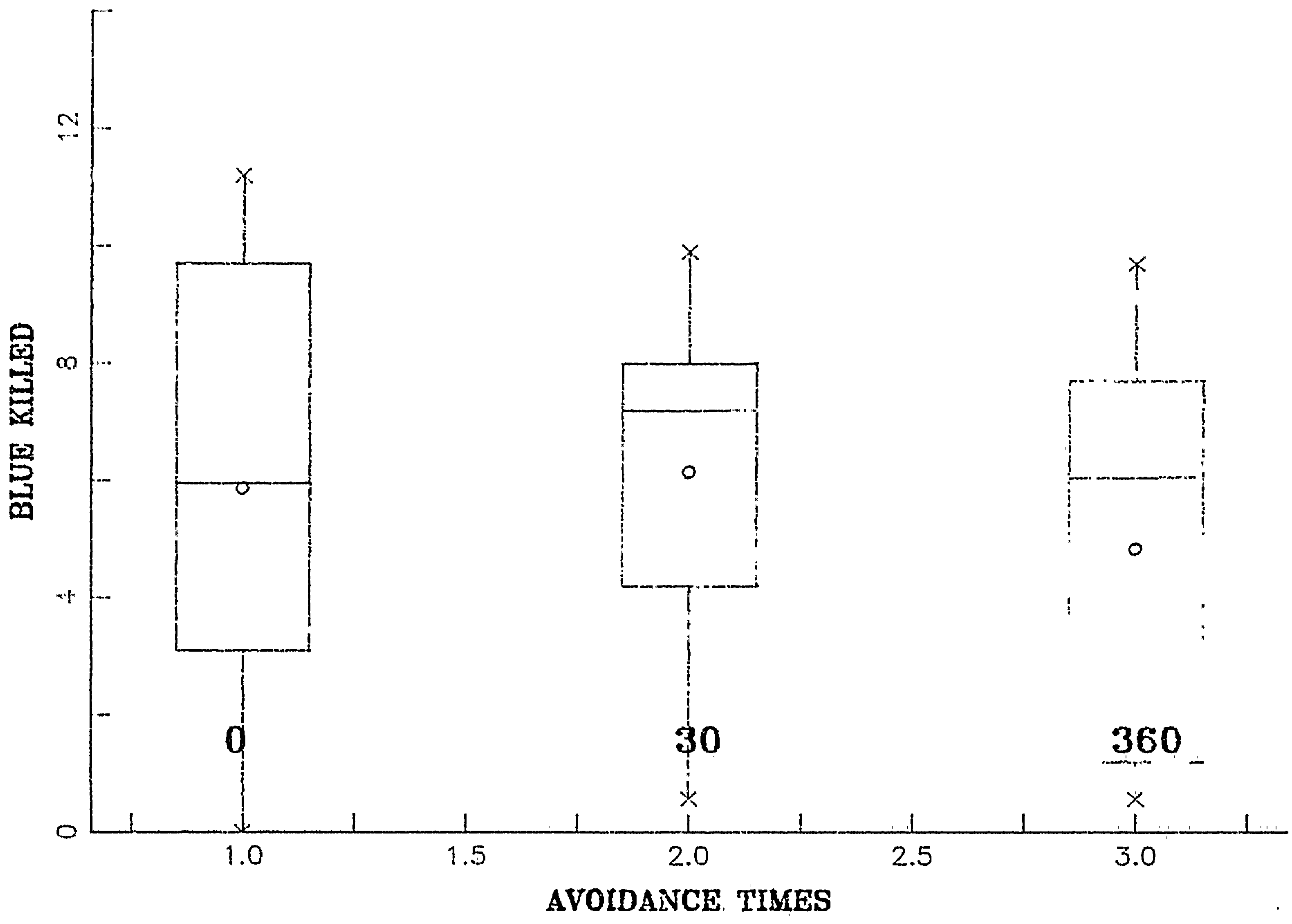


Figure 9

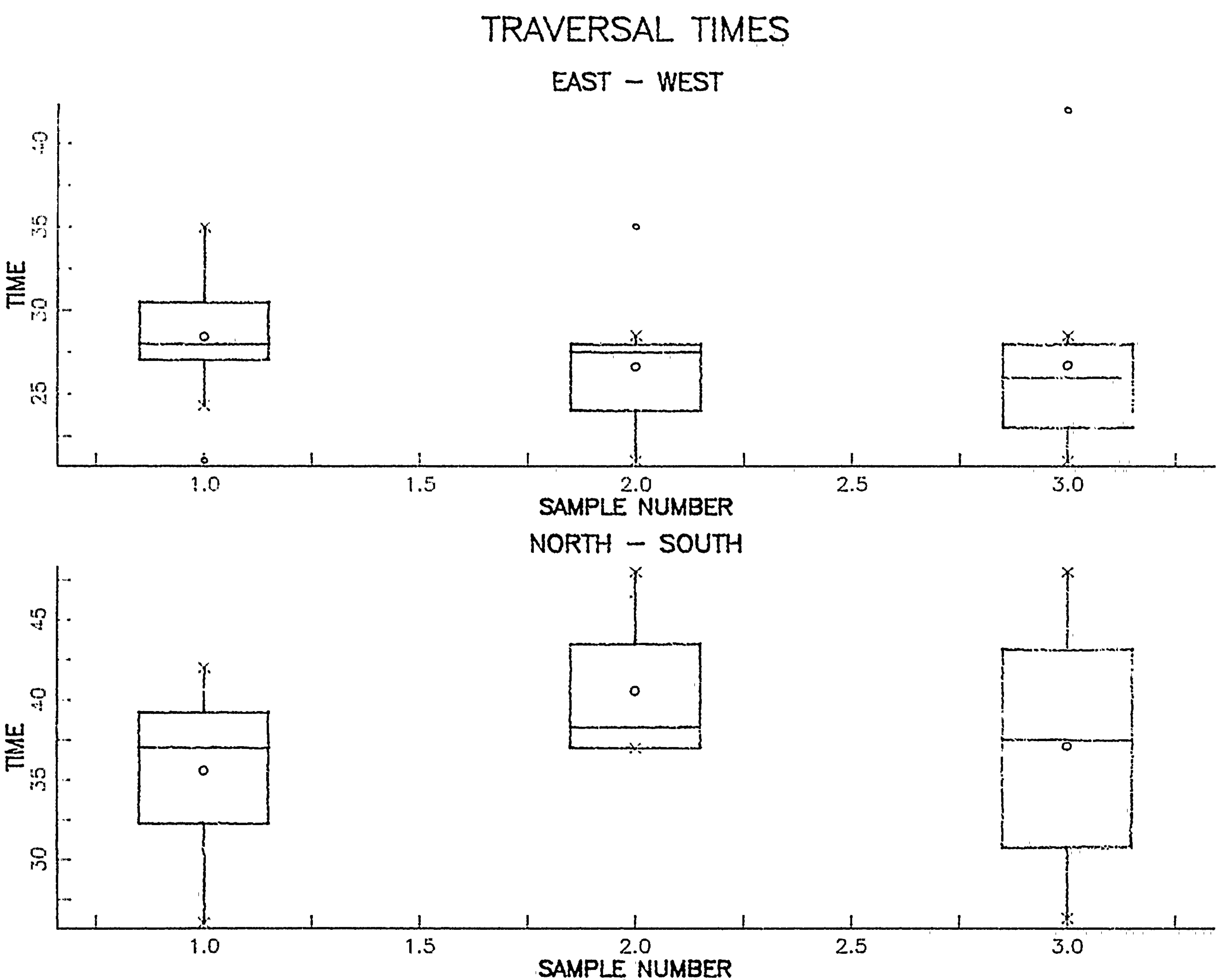

TRAVERSAL TIMES
EAST – WEST
TIME
25
30
35
40
1.0
1.5
2.0
2.5
3.0
SAMPLE NUMBER
NORTH – SOUTH
TIME
30
35
40
45
1.0
1.5
2.0
2.5
3.0
SAMPLE NUMBER

Figure 10

4. Analysis

The CAMMS/Shaw model performed well against the officers in the north-south attack. The model performed especially well in the 30 minute avoidance time route where the CAMMS/Shaw model route did not result in a single casualty up to 1000 meters. This suggests that the model may have some promise. The north-south scenario is in an area where there is a considerable amount of vegetation and contour differences in the terrain. Thus, route selection in this area is especially important as there are covered and concealed routes available. CAMMS/Shaw found these routes better than the officers in this study.

The CAMMS/Shaw model did not perform as well as the officers in the east-west attack. Any of the possible causes previously discussed could have resulted in the performance differences of the CAMMS/Shaw model in the east-west attack. However, in this case one additional explanation of the problem is suggested. The discrepancy could also be explained by the nature of the two scenarios. As stated earlier, the north-south terrain is much more covered and concealed with some rolling forested areas than is the east-west terrain. The east-west terrain is very open with few good routes available. The only cover available is primarily limited to the urban areas and Janus(A) portrays urban areas only in terms of their density [ref 10]. The officers may have performed better because they made greater use of this urban cover and concealment. Perhaps, the particular TMP function used in this CAMMS/Shaw model does not evaluate urban areas effectively.

V. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

A. CONCLUSIONS

The CAMMS/Shaw model could not predict effective routes throughout the range of avoidance times using the single time solution technique and the present TMP function. Additional studies should be performed to determine if the CAMMS/Shaw model is effective over a more limited range of avoidance time values and to validate the TMP function. This study produced some evidence that the CAMMS/Shaw model was valid for avoidance times below 60 minutes.

The CAMMS/Shaw model was significantly more effective than officers in predicting routes in the north-south scenario. In addition, this attack scenario contained more available cover and concealment than the other scenario. This result indicates that when cover is available, CAMMS/Shaw may provide officers with an effective tool for evaluating tactical routes.

The CAMMS/Shaw model did not select routes as well as officers in the east-west attack scenario. This problem could have been caused by a number of factors to include the nature of the scenario. The east-west scenario had very little cover outside of the urban areas and Janus(A) only grossly portrays urban areas. Officers used this urban cover and concealment better than the CAMMS/Shaw model.

Modelers should consider replacing the single time heuristic solution procedure with the Lagrangian relaxation optimization technique. The Lagrangian technique is easier to understand, because it selects the best route for the traversal time available. This procedure avoids the concept of avoidance time neccesary in the single time scale heuristic which could cause confusion and possibly inaccurate results.

The problem in the model with defining the area of operations discussed in Chapter II should be identified and solved. Presently, the user can only define the area of operation after numerous trials. The function fails and an error message is generated approximately 90 percent of the time.

B. RECOMMENDATIONS FOR FUTURE RESEARCH

The effectiveness of CAMMS/Shaw model routes over different avoidance time ranges should be evaluated independent of the performance of officers. This study only evaluated a total of 12 CAMMS/Shaw routes due to the requirement to evaluate officer routes. Concentrating on CAMMS/Shaw routes will allow a larger number of routes to be evaluated. This larger sample size will give a better picture of the CAMMS/Shaw model using the single time heuristic solution technique over the range of avoidance times. Initial studies should focus on routes with avoidance times from 0 to 60 minutes.

Similar studies comparing CAMMS/Shaw against officers in different scenarios should also be considered. These comparisons will provide a larger sample size which could provide more statistical evidence to evaluate the possible effectiveness of the CAMMS/Shaw model as a decision aid. This study could only evaluate two scenarios. A much larger number of scenarios should be evaluated before an informed decision can be made.

The TMP regression should be reexamined with a different population to determine if a similar regression function is obtained. The survey should be done in a more controlled environment such as a TRADOC school. CPT Shaw had to depend on the good nature of graduate students who responded through the mail. Although every effort was made to effectively administer this survey, these officers may not have taken sufficient time to properly respond to all questions.

The CAMMS/Shaw model at TRAC-Monterey does not contain a module which displayed the traversal time as predicted by CAMMS. A version of the CAMMS/Shaw model which contains this module should be obtained. Then, the routes at the different avoidance times and their predicted traversal times could be compared. The comparison could determine whether the CAMMS/Shaw model traversal times decrease as avoidance time increased. This comparison would be a direct test of the algorithm independent of another model. If the CAMMS model predicted that routes with higher avoidance times were faster than routes with lower avoidance times, then one could conclude that the algorithm is definitely faulty. This conclusion would be necessary because CAMMS is the data source of the CAMMS/Shaw model for traversal speed.

This study used the default unit formation of Janus(A). Similar studies could also be performed with other unit formations. In addition, other high resolution combat models could be used.

APPENDIX A. THE JANUS(A) MODEL

A. GENERAL

Before any comparisons of routes can be accomplished, the model that simulates the combat must be understood. This understanding is important, because every model is only an abstraction of reality. Therefore, the results are only valid within the framework of the model assumptions. This appendix explains some of the key features and abstractions of the Janus(A) combat model that were used in building the scenario.

The Janus(A) model consists of approximately 85,000 lines of FORTRAN source code. It was developed for the Army by Lawrence Livermore Laboratories in California. The chief Army proponent for the model is the Training and Doctrine Command Analysis Center at White Sands Missile Range, New Mexico. The model is approved by the Army Models Board and is widely used to conduct studies on a variety of Army problems.

The particular model used for this study runs on a VAX/VMS system at TRAC - Monterey. The user interacts with a keyboard and a black and white monitor to communicate scenario building selections and changes to the model.

The Janus(A) model has two modes: systemic processing and man-in-the-loop (normal). The systemic processing mode is used after a base case scenario is developed by the modeler. The modeler uses systemic processing because of the stochastic nature of Janus(A) and because of the relative speed of systemic processing. The stochastic nature of the model requires multiple repetitions (normally 30-40) in order to determine the variance in the results. Systemic processing can complete these 30 to 40 runs much faster than the normal mode. The main reason for the relative speed is that the systemic mode does not display the battle graphically. In the systemic processing mode only casualty figures and related data are displayed on the screen. The normal mode, on the other hand, graphically displays the weapon systems as they maneuver on the terrain. The normal mode is used to build a base case scenario and for interactive combat modeling. The base case scenario includes the weapon systems, routes, obstacles, and many other features that are used to simulate combat. The interactive feature allows a user to change inputs, such as routes, at any time in the battle. In the normal mode an additional color monitor with high resolution graphics is used. The color monitor displays the forces as they employ fire and maneuver on the battlefield. Separate monitors for red and blue forces are used. The red force monitor only displays the red deployment and the blue forces that the red force can observe. The blue monitor displays similar graphics for blue. Engagements as well as kills are also displayed on the screen [ref 11 pp:9-16]. The entire hardware configuration is shown in Figure 11.

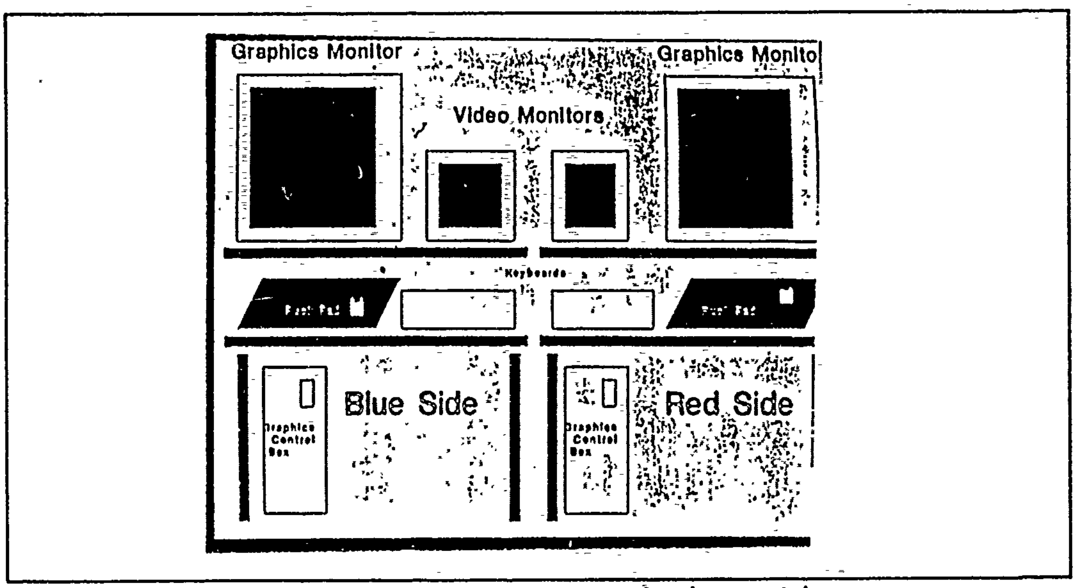


Figure 11 The Janus(A) hardware configuration.

B. BUILDING WEAPON SYSTEMS

Weapon systems in Janus(A) consist of specified number of individual weapons grouped together to build the system. For example, a tank weapon system might consist of the main gun, an M-60 machinegun and a coaxial .50 cal machinegun. Each of these weapon systems would have various probability of hit, and probability of kill/hit tables as functions of range associated with it. The tables would correspond to the various modes of engagement between two weapon systems. For example, one mode of engagement might be a stationary tank in defilade engaging a moving exposed tank on its flank with its main gun. Thus, a weapon system might have a large number of probability tables associated with it. In addition some weapons cannot engage other weapons at all. The three weapon systems used in this study were built using the Army Material Scientific Support Agency (AMSSA) data base.

C. BUILDING UNITS

Units are built using the Forces Editor. The user builds a force using the weapon systems that he has already created. The force may contain any combination of the previously designated weapon systems. The force can be built using single or aggregated weapon systems. A force containing ten single weapon systems would display each weapon system on the Janus(A) screen. Each of these weapon systems would require a separate route designated for it. A force containing an aggregated unit with ten weapon systems requires display of only a single weapon system on the Janus(A) screen. This aggregated weapon system would require only a single route designated for the entire unit. The weapon systems in the unit move on that route in a column formation until they are firing on the enemy. Then, the unit deploys into an on-line formation. Aggregated units may contain up to 15 weapon systems [ref 10].

D. TERRAIN

Terrain in Janus(A) is not as detailed as the terrain in the CAMMS model. Janus(A) terrain consists only of elevation and vegetation/urban density data for 100 meter cells [ref. 10]. This could become a limitation when evaluating the CAMMS model with Janus(A). Janus(A) may not be able to resolve subtle differences between different pieces of terrain that result from soil or climate conditions.

Terrain affects a host of functions in the model from unit movement to target acquisition. The effects on the major sections are discussed in subsequent paragraphs.

E. FIRE CONTROL

The NVEOL Acquisition Model is a key module used in Janus(A). This model controls an LOS module which uses the elevation and vegetation data to calculate whether LOS exists between the observer and his target. This LOS is updated every six seconds. Once LOS is obtained, the cumulative probability of acquisition is computed at fixed time intervals until acquisition occurs. Then, the weapon system appears on the unit's target list where it can be engaged. The engagement takes place based on the priority of the target and the capabilities of the acquiring weapon system. If a target is available and the acquiring weapon system has ammunition, the acquiring system will normally engage the target unless a fire discipline feature is used [ref 7: pp 23-40].

Fire discipline can be modeled in two ways. First, range priorities can be set by weapon and ammunition type while building the scenario. Also, in the interactive mode, weapons can be placed in a hold fire status making it impossible to fire. However, neither of these fire discipline measures were used because they would create another variable (opponent fire discipline strategy) which would have to be studied separately.

F. MANEUVER ROUTES

Maneuver in Janus(A) begins when a unit is deployed using the interactive version of the model. A mouse is used to select the exact position a unit will be deployed on the graphical terrain representation. Then, the unit's individually prescribed route is input into the model until the plan is complete. All routes in Janus(A) are piecewise linear. The route is input by selecting a number of sequential points anywhere in the terrain grid. The weapon system then moves in a straight line from point to point until it completes its route.

Once the plan is complete and the simulation begins, the unit moves at a speed determined by three conditions. The three conditions are the maximum assigned speed of vehicle itself, the maximum assigned speed of the unit to which the vehicle is attached (the group speed), and the terrain conditions. The terrain affects movement speed based on the terrain slope and the density of vegetation/urban areas. The minimum of these three speeds determines the rate of movement [ref 11: pp 55-69].

G. OTHER EFFECTS

There are a host of other effects in the model that are not discussed here. These effects include suppression, nuclear fires, artillery, engineering obstacles, and the mission oriented protective posture (MOPP) employed to combat nuclear,biological and chemical fires. More detailed information on these effects and the other features already discussed can be obtained from the various Janus(A) references listed in the bibliography.

H. BUILDING A BASE CASE SCENARIO AND SYSTEMIC JANUS(A)

The next step is to build a base case scenario. The purpose of this procedure is to verify the simulated battle before beginning systemic processing. An essential step in building this base case scenario is weapon system verification to ensure that correct weapon systems exist and that proper relationships between the weapon systems exist. Janus(A) has several features to help in weapon system verification. One such feature graphically displays the relationships that exist between weapon systems so that problems can be easily identified. The next step is to observe the ensuing battle on the interactive screen to insure that the battle unfolds properly. Any inconsistencies or unusual occurrences, such as weapon systems not firing, indicate problems with model data inputs. These problems must be corrected before proceeding with systemic processing. In addition, battle termination conditions are also important. For example, if the battle last too long weapon systems may run out of ammunition or the entire force may be killed on every run, thus biasing the results. On the other hand, if the battle is to short, key data may be lost. A base case scenario must be run for every route entered before systemic processing begins.

Once the base case scenario is properly built and the battle termination conditions (time) have been determined, the user may proceed with systemic processing. Systemic processing is necessary because of the stochastic nature of

Janus(A). Systemic processing runs much faster than normal model runs as no graphics are required. Only casualty reports and related information are generated.

APPENDIX B. OFFICER TACTICAL ROUTE SURVEY

TACTICAL ROUTE SURVEY

The purpose of this survey is to evaluate a tactical route decision aid that the Army may provide to tactical commanders in the future. The decision aid is designed to determine an "optimal" tactical route between two points on a battlefield. I am asking your help to assist me in determining whether this tool is a good investment for the Army. You will be asked to select routes for a heavy company / team in two offensive scenarios. The routes will be from a company assembly area to an assault position. The scenarios are simple and the entire survey should take no more than twenty minutes.

Your routes, the routes of other Army and Marine officers, and the routes determined by the decision aid will then be input into the Janus(A) combat simulation to provide a comparison based on combat results. I will use several different measures of effectiveness to make the comparison. The basic question I am trying to answer is whether the decision aid can perform better than experienced Army and Marine officers such as yourself.

I will also ask you to provide me some simple background information on your career experiences. However, I assure you that your survey results will remain confidential and that only general results will be reported in my thesis. I would also request that you return the survey in the envelope provided no later than 1 July 90 so that your results can be included in my thesis.

I want to thank you in advance for your assistance and wish you the best of luck in your curriculum and with your thesis.

Sincerely,

John S. Regan

CPT,USA

Operation Analysis Curriculum

PART ONE -BACKGROUND INFORMATION

Please circle the correct response or fill in the blank.

1. I am a Marine / Army officer.
2. My paygrade is O-1 / O-2 / O-3 / O-4 / O-5.
3. I have served in combat arms tactical units for ________ years and _______ months.
4. I was a platoon leader for _______ years and _______ months.
5. I served on a battalion staff for ________ years and _______ months.
6. I served as a company commander for ________ years and _______ months.
7. My basic branch is _________.
8. I have completed _______ years and _______ months of commissioned service.

PART TWO - GENERAL SCENARIO

You are the commander of Team Yankee. You are presently located at company assembly area green (see Figure 12). You have prepared paragraphs one and two of your operations order from the Task Force 1-15 extract. You have issued a warning order and your platoon leaders report that they are logistically prepared to attack. You are now about to select your route and prepare parar ph three, Concept of the Operation.

Please review paragraphs one and two of your operations order and overlay one (see Figure 12).

1.Situation.

a.Task Organization:

Team Yankee/TF 1-15 (-)

2 Mech. Plts (M2)	1 Tank Plts (M1)	Team HQ
1 Engineer Sqd. w/CEV	1 Stinger	1 Fist

b.Enemy Forces:

Unidentified forces of the Soviet 111TH MRR are defending in sector. The enemy is estimated tc be at 72% strength in men, equipment, and supplies. They are preparing defensive positions. The enemy is equipped with organic BMP IFV's and BRDM ATV's as well as being reinforced by a T80 Guards Tank Battalion. Expect enemy artillery support from the RAG using 122 SP's. Other artillery support is also possible. The enemy may receive Helo support in the form of HIP or HIND-D units if our operations are successful. The status of enemy fixed wing support is not known at this time. The enemy has positions about 5 kilometers away. Identified enemy units and positions are provided on the intelligence overlay. Other larger enemy forces are known to be preparing positions behind their security zone.

c.Friendly Forces:

Task Force 1-15 attacks to seize Objective George as part of the 10th Brigade. Team Whiskey and Zulu of TF 1-15 are on our left and right respectively. The task force has a Battalion of 155 SP's in direct support. Teams Whiskey,Yankee and Zulu will attack abreast in order to achieve the Task Force objective. Team Xray is in reserve.

2.Mission.

Team Yankee /TF 1-15 will cross phase line Blue NLT 180500Z and attack the high ground vic Objective Sam NLT xxxxZ (see requirements 1-3) in order to seize Objective Sam. Team Yankee will then defend in place until relieved.

GENERAL INFORMATION

1)Do not cross Phase Lines Stop (Area one) or Hold (Area Two).

2)Average unit speed is 40 Km per hour.

3)All streams are easily fordable.

Figures 12 and 13 are substituting for actual overlays that were used in the survey. These figures graphically portray the tactical situation. Figure 12 shows the east-west attack scenario used in area of operation one. Figure 13 on page 78 shows the north-south attack scenario used in area of operation two.

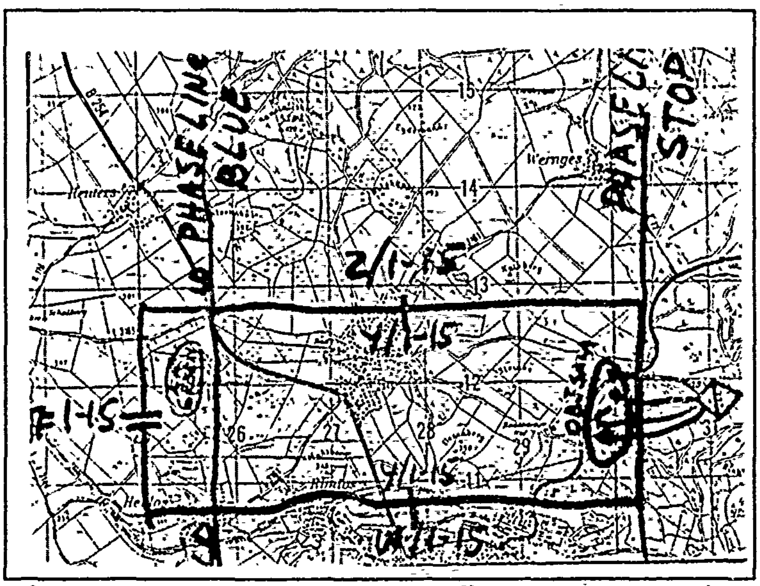


Figure 12 The East-West Attack Scenario.

AREA OF OPERATIONS ONE

REQUIREMENT ONE

Assume you receive overlay one as the intelligence update from battalion (see Figure 12). The overlay has a note on it from the battalion commander which states, "This is the latest intelligence. I have checked it and it is very reliable. I need you to proceed to your objective as quickly as possible once you cross phase line blue. The timing of your attack is critical to the brigade plan. Plan accordingly."

Please draw on Overlay One the movement route that your unit would follow as it moves from the assembly area to Objective Sam. Please ensure that you draw only one route on the overlay. If you would use multiple routes please draw the route that best describes the center of mass of the company team.

REQUIREMENT TWO

Assume instead that you receive the same overlay, but a different note from your battalion commander. The note attached to it from your battalion commander states: "This is the latest intelligence. I have checked and it is very reliable. The timing of your attack is important, but I don't want you to waste combat power. Your route may take up to 30 minutes to avoid a major engagement prior to the objective. Plan accordingly."

Please familiarize yourself with Overlay Two. Remember that you can take 30 minutes to avoid a premature major engagement prior to the objective once you cross phase line Blue.

If your route will change (from Overlay One) with this additional time, please draw it on Overlay Two. If your route does not change write no change on Overlay Two. Once again please indicate only one route on the overlay.

REQUIREMENT THREE

Assume that everything is exactly the same as REQUIREMENT TWOexcept that now may take as much time as you would like to maneuver to the objective.

If your route will change (from Overlay Two) with this additional time, please draw it on Overlay Three. If your route does not change write no change on Overlay Three. Once again please indicate only one route on the overlay.

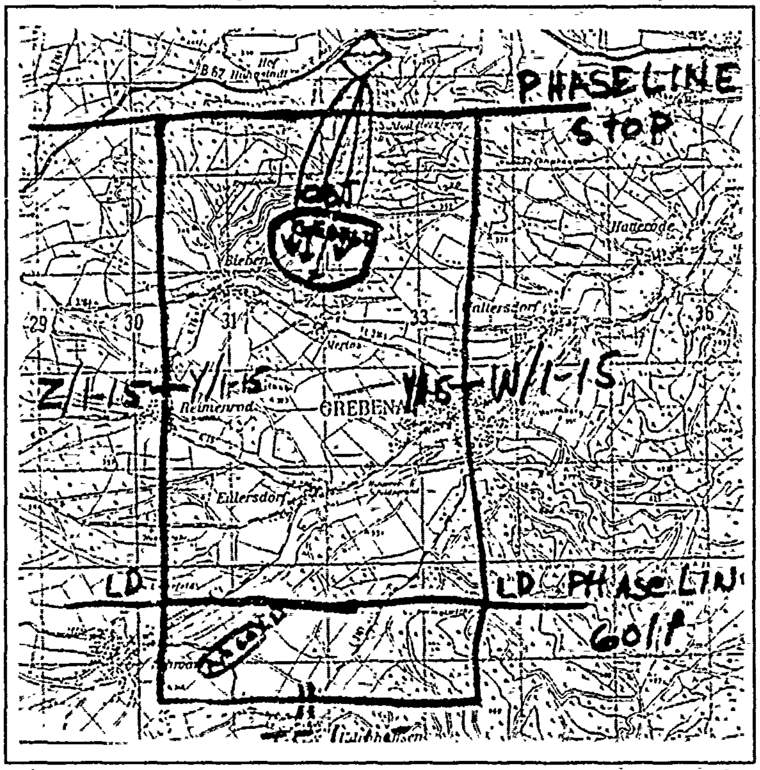


Figure 13 The North-South Attack Scenario

AREA OF OPERATIONS TWO

This section repeats the requirements of Area of Operations One for a slightly different area of operations. You are still the commander of Team Yankee. You are now located at a company assembly area Gold (see Figure 13). Everything else is exactly the same as in Area of Operation One except that the mission has changed slightly (see below) to reflect the new area (see Figure 13). To refresh your memory the scenarios (from Area of Operation One) are repeated before each requirement. However, if you completely recall the scenarios, you need only read and complete the requirement on the overlays. Your new mission is:

2.Mission

Team Yankee /TF 1-15 will cross phase line Golf NLT 180500Z and attack the high ground vic Objective Uncle NLT 18xxxxZ (see requirements 4-6) in order to seize Objective Uncle. Team Yankee will then defend in place until relieved.

REQUIREMENT FOUR

Assume you receive overlay four (see Figure 13)as the intelligence update from battalion. The overlay has a note on it from the battalion commander which states, "This is the latest intelligence. I have checked it and it is very reliable. I need you to proceed to your objective as quickly as possible once you cross phase line blue. The timing of your attack is critical to the brigade plan. Plan accordingly."

Please draw on Overlay Four the movement route that your unit would follow as it moves from the assembly area to Objective Uncle. Please ensure that you draw only one route on the overlay. If you would use multiple routes please draw the route that best describes the center of mass of the company team.

REQUIREMENT FIVE

Assume instead that the intelligence remains the same, but you receive a different note from your battalion commander. The note from your battalion commander states: "This is the latest intelligence. I have checked and it is very reliable. The timing of your attack is important, but I don't want you to waste combat power. Take up to 30 minutes to avoid a premature major engagement prior to the objective. Plan accordingly."

Please familiarize yourself with Overlay Five. Remember that you can take up to 30 minutes to avoid a major engagement once you cross phase line Golf.

If your route will change (from Overlay Four) with this additional time, please draw it on Overlay Five. If your route does not change write no change on Overlay Five. Once again please indicate only one route on the overlay.

REQUIREMENT SIX

Assume that everything is exactly the same as REQUIREMENT FIVE except that now may take as much time as you would like to maneuver to the objective.

If your route will change (from Overlay Five)with this additional time, please draw it on Overlay Six. If your route does not change write no change on Overlay Six. Once again please indicate only one route on the overlay.

This completes the survey. Thank you for your help.

APPENDIX C. TABULATED RESULTS

CAMMS/SHAW RESULTS

Complete Route

ATTACK TYPE	AVOIDANCE TIME	MEAN NUMBER OF BLUE KILLED	VARIANCE OF BLUE KILLED
NORTH-SOUTH	0	8.4	1.87
NORTH-SOUTH	30	4.7	0.94
NORTH-SOUTH	60	5.1	1.49
NORTH-SOUTH	200	13.8	0.46
NORTH-SOUTH	300	7.1	1.37
NORTH-SOUTH	330	5.7	1.6
EAST-WEST	0	11.1	2.43
EAST-WEST	30	7.9	2.7
EAST-WEST	90	11.6	2.53
EAST-WEST	135	7.83	2.44
EAST-WEST	200	12.0	1.11
EAST-WEST	300	10.1	2.41

CAMMS/SHAW RESULTS

AT 1000 METERS

ATTACK TYPE	AVOIDANCE TIME	MEAN NUMBER OF BLUE KILLED	VARIANCE OF BLUE KILLED
NORTH-SOUTH	0	7.2	1.96
NORTH-SOUTH	30	0	0
NORTH-SOUTH	60	2.67	1.32
NORTH-SOUTH	200	11.5	2.51
NORTH-SOUTH	300	7.1	1.37
NORTH-SOUTH	330	5.1	1.35
EAST-WEST	0	11.1	2.43
EAST-WEST	30	7.9	2.7
EAST-WEST	90	11.6	2.52
EAST-WEST	135	7.83	2.44
EAST-WEST	200	12.0	2.45
EAST-WEST	300	10.0	2.47

COMPLETE ROUTE

NORTH-SOUTH ATTACK

AVOIDANCE TIME - 0 MINUTES

SUBJECT	MEAN	VARIANCE
CAMMS	8.1	1.96
OFFICER 1	0	0
OFFICER 2	6.4	2.1
OFFICER 3	7.2	1.68
OFFICER 4	13.1	0.46
OFFICER 5	0.6	1.13
OFFICER 6	5.5	1.83
OFFICER 7	10.9	1.75
OFFICER 8	11.2	1.78
OFFICER 9	9.7	2.33
OFFICER 10	3.1	0.96
OFFICER MEAN	9.2	3.79

COMPLETE ROUTE

NORTH-SOUTH ATTACK

AVOIDANCE TIME - 30 MINUTES

SUBJECT	MEAN	VARIANCE
CAMMS	4.7	0.94
OFFICER 1	8.0	2.81
OFFICER 2	6.6	1.94
OFFICER 3	7.23	1.68
OFFICER 4	13.1	0.80
OFFICER 5	5.5	1.7
OFFICER 6	13.8	0.91
OFFICER 7	9.9	2.11
OFFICER 8	13.8	0.91
OFFICER 9	11.2	1.48
OFFICER 10	5.7	1.44
OFFICER MEAN	9.4	3.2

COMPLETE ROUTE

NORTH-SOUTH ATTACK

AVOIDANCE TIME - MAXIMUM MINUTES

SUBJECT	MEAN	VARIANCE
CAMMS	5.7	1.6
OFFICER 1	5.2	2.2
OFFICER 2	3.27	1.2
OFFICER 3	7.23	1.78
OFFICER 4	13.8	0.46
OFFICER 5	13	1.46
OFFICER 6	9.7	2.9
OFFICER 7	9.9	2.11
OFFICER 8	10.6	2.66
OFFICER 9	11.2	1.48
OFFICER 10	5.7	1.44
OFFICER MEAN	8.96	3.48

COMPLETE ROUTE

EAST-WEST ATTACK

AVOIDANCE TIME - 0 MINUTES

SUBJECT	MEAN	VARIANCE
CAMMS	11.1	2.43
OFFICER 1	5.23	1.82
OFFICER 2	5.8	1.79
OFFICER 3	5.73	1.83
OFFICER 4	4.37	1.73
OFFICER 5	7.7	3.5
OFFICER 6	9.2	2.6
OFFICER 7	5.29	1.48
OFFICER 8	4.17	2.1
OFFICER 9	7.1	2.46
OFFICER 10	7.6	2.58
OFFICER MEAN	6.21	1.6

COMPLETE ROUTE

EAST-WEST ATTACK

AVOIDANCE TIME - 30 MINUTES

SUBJECT	MEAN	VARIANCE
CAMMS	7.9	2.7
OFFICER 1	6.7	2.13
OFFICER 2	5.8	1.79
OFFICER 3	6.2	1.77
OFFICER 4	2.7	1.86
OFFICER 5	4.97	1.96
OFFICER 6	9.0	2.51
OFFICER 7	6.29	2.2
OFFICER 8	9.09	2.67
OFFICER 9	7.1	2.46
OFFICER 10	5.5	1.70
OFFICER MEAN	6.3	1.87

COMPLETE ROUTE

EAST-WEST ATTACK

AVOIDANCE TIME - MAXIMUM MINUTES

SUBJECT	MEAN	VARIANCE
CAMMS	10.2	2.7
OFFICER 1	7.8	3.1
OFFICER 2	7.7	2.67
OFFICER 3	6.2	1.77
OFFICER 4	2.7	1.86
OFFICER 5	4.97	1.96
OFFICER 6	9.0	2.51
OFFICER 7	6.29	2.2
OFFICER 8	8.57	2.10
OFFICER 9	7.1	2.46
OFFICER 10	5.5	1.70
OFFICER MEAN	6.5	2.0

NORTH-SOUTH ATTACK

AVOIDANCE TIME - 0 MINUTES

AT 1000 METERS

SUBJECT	MEAN	VARIANCE
CAMMS	7.2	1.96
OFFICER 1	0	0
OFFICER 2	6.4	2.1
OFFICER 3	7.2	1.68
OFFICER 4	4.2	1.5
OFFICER 5	0.6	1.13
OFFICER 6	5.5	1.83
OFFICER 7	10.9	1.75
OFFICER 8	11.2	1.78
OFFICER 9	9.7	2.33
OFFICER 10	3.1	0.96
OFFICER MEAN	5.88	3.99

NORTH-SOUTH ATTACK

AVOIDANCE TIME - 30 MINUTES

AT 1000 METERS

SUBJECT	MEAN	VARIANCE
CAMMS	0	0
OFFICER 1	8.0	2.81
OFFICER 2	6.4	2.07
OFFICER 3	7.2	1.68
OFFICER 4	4.2	1.5
OFFICER 5	0.73	1.3
OFFICER 6	7.2	2.0
OFFICER 7	7.7	2.0
OFFICER 8	9.9	1.47
OFFICER 9	9.7	2.33
OFFICER 10	0.57	1.33
OFFICER MEAN	6.16	3.32

NORTH-SOUTH ATTACK

AVOIDANCE TIME - MAXIMUM MINUTES

AT 1000 METERS

SUBJECT	MEAN	VARIANCE
CAMMS	5.1	1.35
OFFICER 1	5.2	2.2
OFFICER 2	1.4	1.2
OFFICER 3	7.2	1.68
OFFICER 4	1.2	1.35
OFFICER 5	0.73	1.3
OFFICER 6	6.9	2.5
OFFICER 7	7.7	2.0
OFFICER 8	7.8	2.0
OFFICER 9	9.7	2.3
OFFICER 10	0.57	1.33
OFFICER MEAN	4.87	3.3

EAST-WEST ATTACK

AVOIDANCE TIME - 0 MINUTES

AT 1000 METERS

SUBJECT	MEAN	VARIANCE
CAMMS	11.1	2.43
OFFICER 1	5.23	1.82
OFFICER 2	5.8	1.79
OFFICER 3	5.3	1.80
OFFICER 4	4.37	1.73
OFFICER 5	7.7	3.5
OFFICER 6	7.2	1.95
OFFICER 7	5.2	1.48
OFFICER 8	4.17	2.1
OFFICER 9	7.0	2.4
OFFICER 10	7.6	2.5
OFFICER MEAN	5.96	1.31

EAST-WEST ATTACK

AVOIDANCE TIME - 30 MINUTES

AT 1000 METERS

SUBJECT	MEAN	VARIANCE
CAMMS	7.9	2.7
OFFICER 1	6.47	2.13
OFFICER 2	5.8	1.79
OFFICER 3	6.2	1.77
OFFICER 4	2.7	1.86
OFFICER 5	3.7	1.68
OFFICER 6	6.8	1.74
OFFICER 7	6.29	2.2
OFFICER 8	9.2	2.2
OFFICER 9	7.0	2.4
OFFICER 10	5.5	1.7
OFFICER MEAN	5.97	1.78

EAST-WEST ATTACK

AVOIDANCE TIME - MAXIMUM MINUTES

AT 1000 METERS

SUBJECT	MEAN	VARIANCE
CAMMS	10.2	2.7
OFFICER 1	7.8	3.1
OFFICER 2	7.4	2.66
OFFICER 3	6.1	1.7
OFFICER 4	2.7	1.86
OFFICER 5	3.7	1.6
OFFICER 6	5.2	1.7
OFFICER 7	6.3	2.2
OFFICER 8	8.57	2.10
OFFICER 9	7.0	2.4
OFFICER 10	5.5	1.7
OFFICER MEAN	6.02	1.8

APPENDIX D. CAMMS/SHAW ROUTES

This appendix depicts the CAMMS/Shaw routes in the east-west attack scenario for selected avoidance times in Figures 14 to 25. The Figures were obtained from the CAMMS/Shaw model at TRAC-Monterey using a color Epson printer. The map sheet is a representation of the Lauterbach area of central Germany. Briefly, each point on the map can be described by map grid coordinates which correspond to the vertical and horizontal position on the Cartesian coordinate system. The scale of the map is 1:50,000 The color and patterns on the map represent contour elevations as follows:

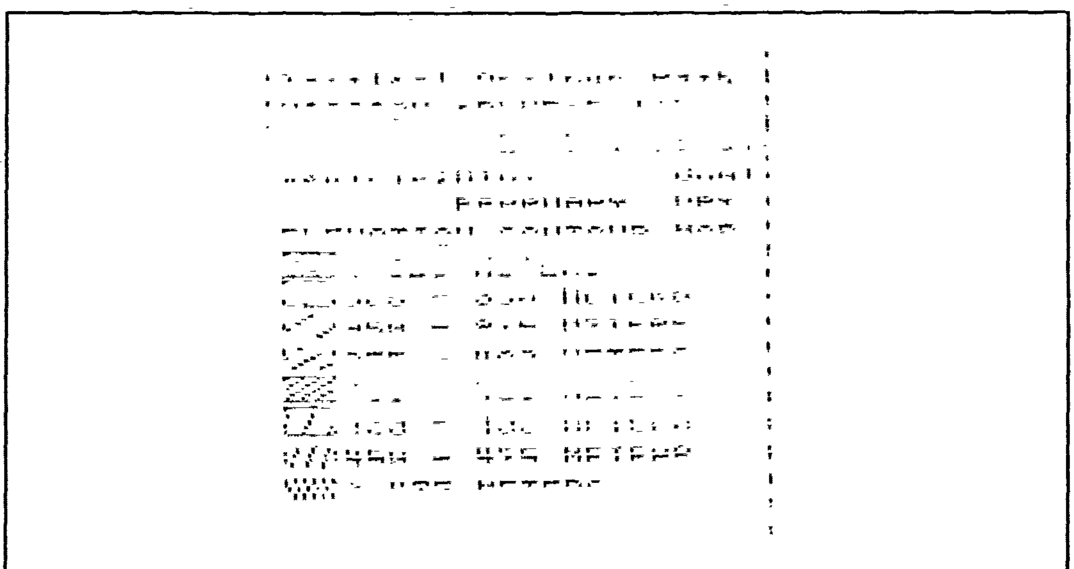


Figure 14 The CAMMS/Shaw map legend.

The route changes are briefly described in the following paragraphs:

Figure 16. The route is the same as Figure 15. This result is consistent as the algorithm does not consider TMP for the 0 avoidance time route.

Figure 17. Route changes slightly to a more northern approach.

Figure 18. Route remains in the north, but slightly different than the 10 minute route.

Figure 19. Route changes completely to a southern sector approach.

Figure 20. Route is slightly different, but still in the southern sector.

Figure 21. Route is moving towards the center, but still in the southern sector. Figure 22. Route is still moving towards the center and still in the southern sector.

Figure 23. Route has shifted dramatically to the north.

Figure 24. Route has shifted dramatically again.

Figure 25. Once again, route shifts dramatically.

Figure 26. Route shifts dramatically towards the end of the approach.

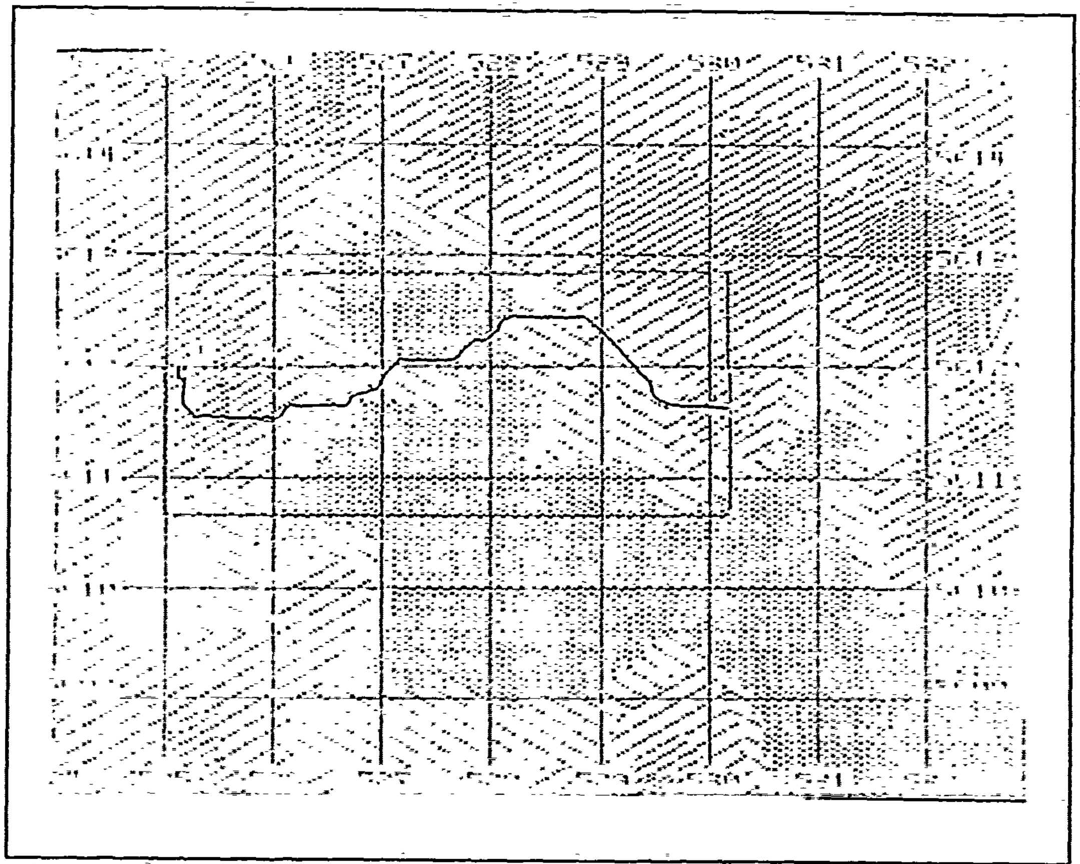


Figure 15 CAMMS/Shaw route with no enemy / 0 min avoidance time.

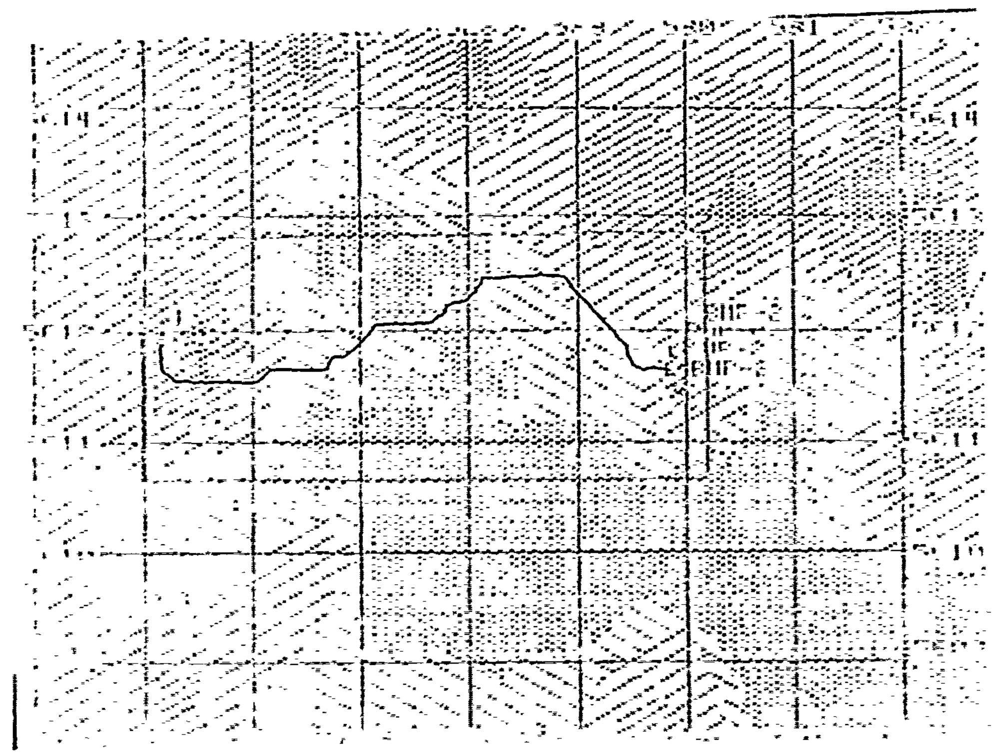


Figure 16 CAMMS/Shaw route with 4 BMP and 0 minute avoidance time.

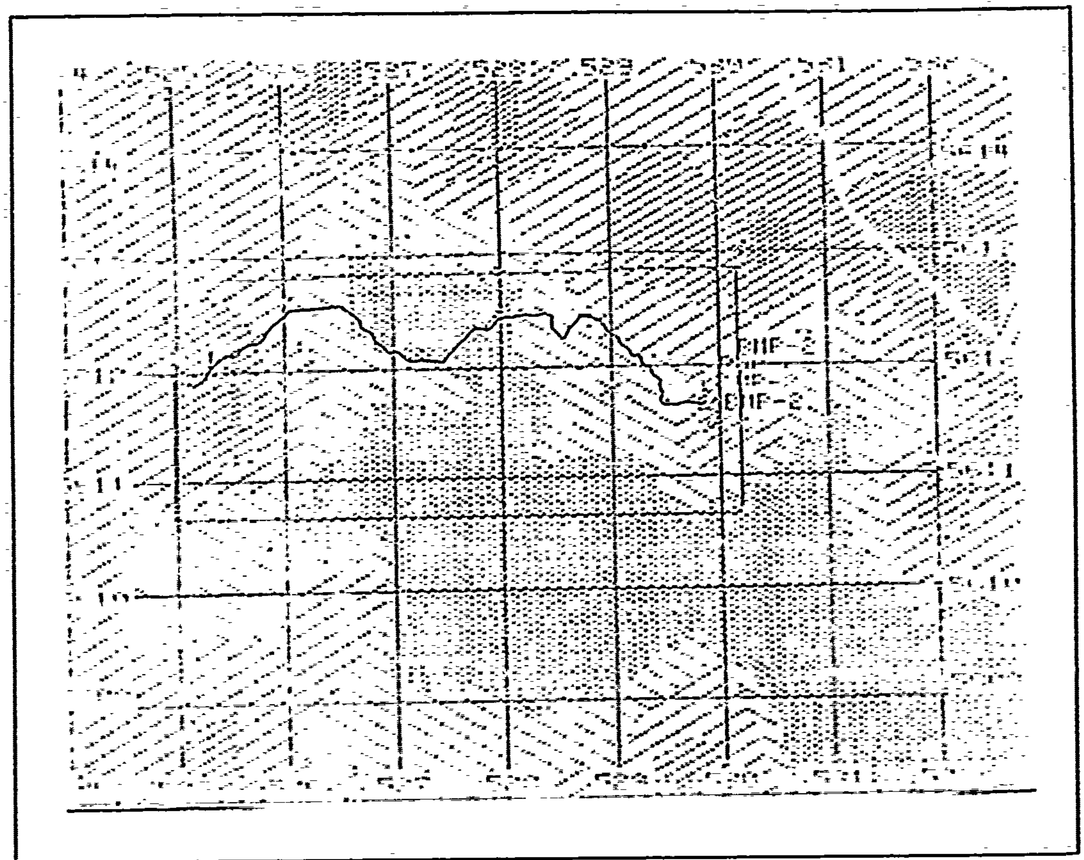


Figure 17 CAMMS/Shaw route with 10 minute avoidance time/4 BMP.

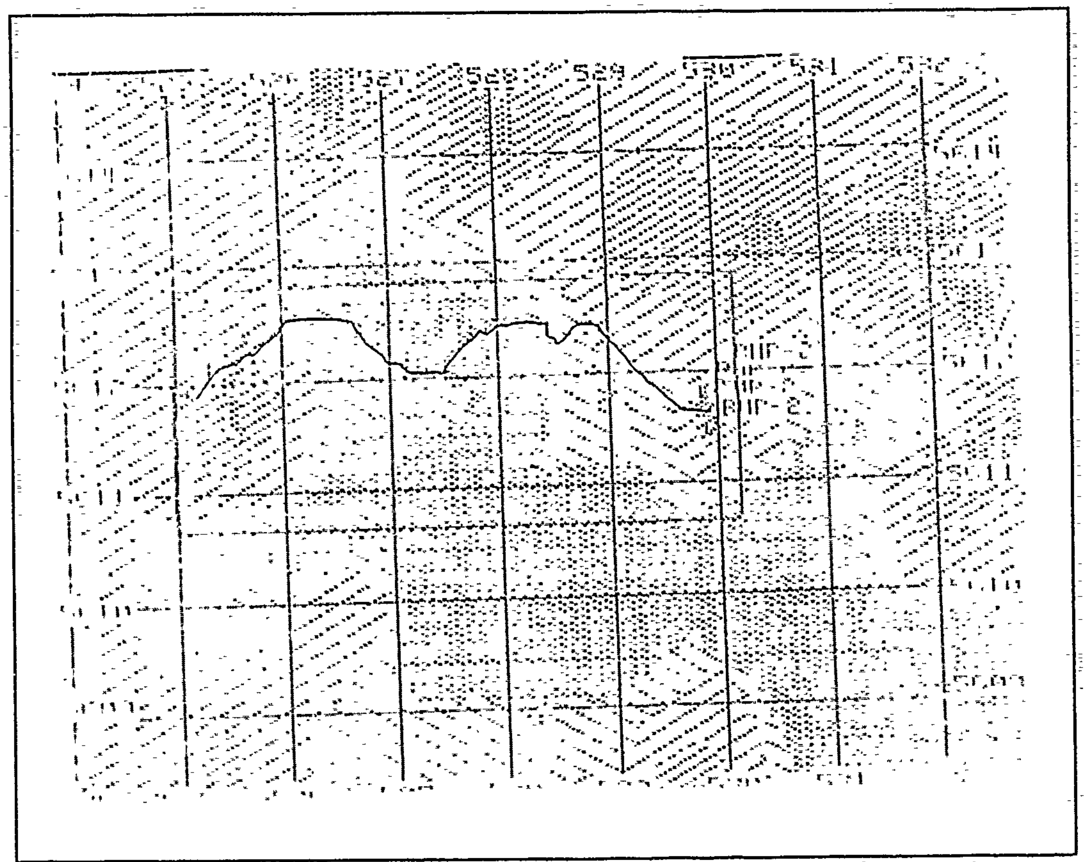


Figure 18 CAMMS/Shaw route with 4 BMP/20 minute avoidance time.

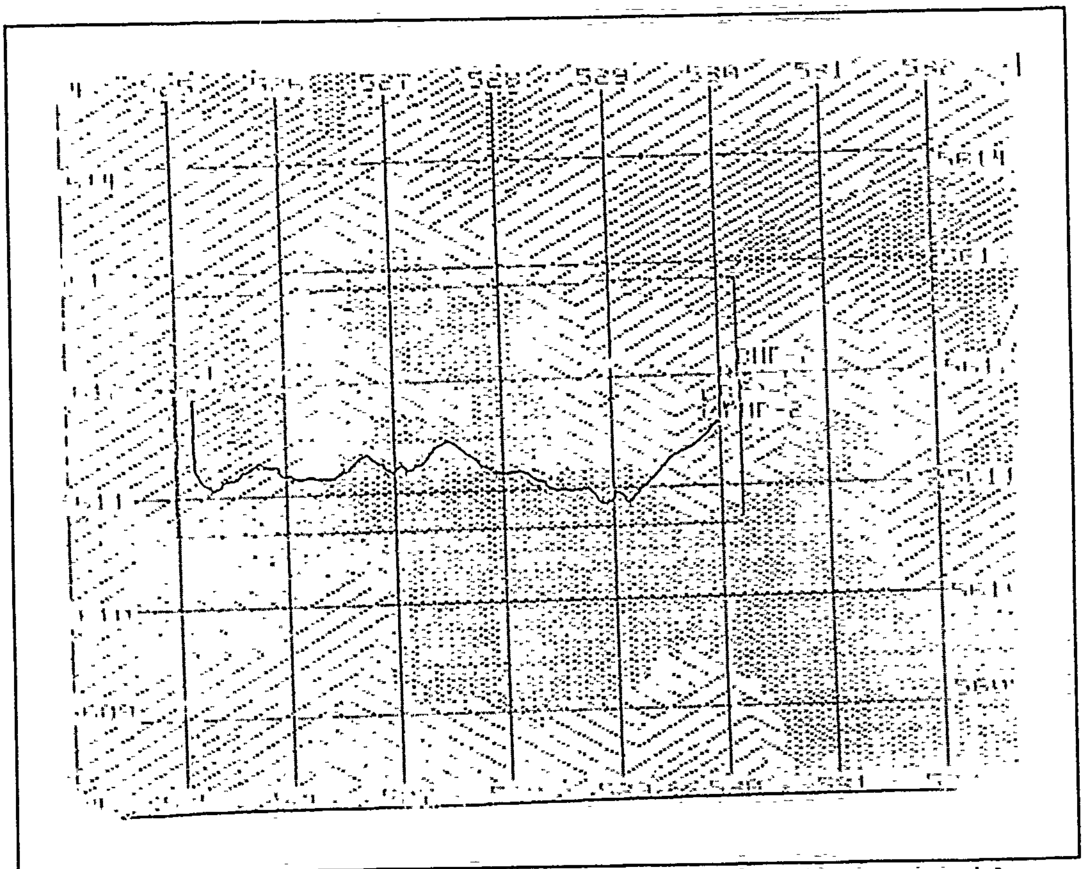


Figure 19 CAMMS/Shaw route with 4 BMP/30 minute avoidance time.

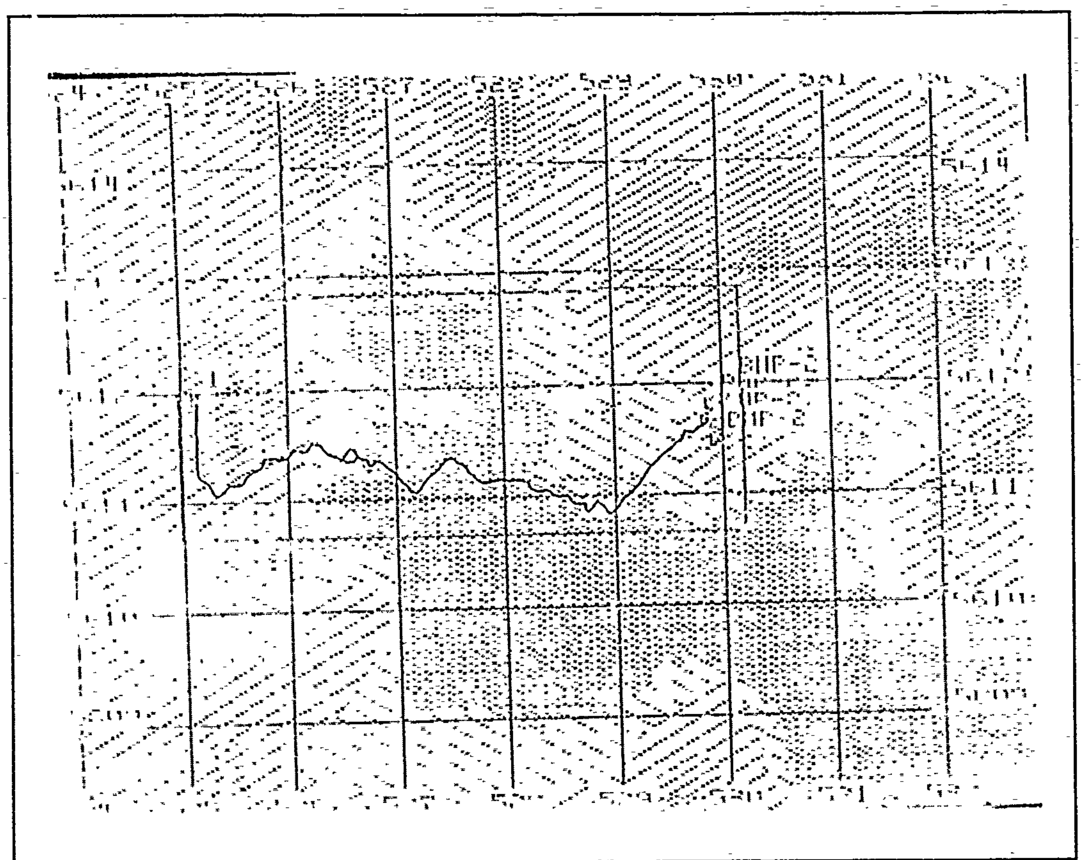


Figure 20 CAMMS/Shaw route with 40 minute avoidance time/4 BMP.

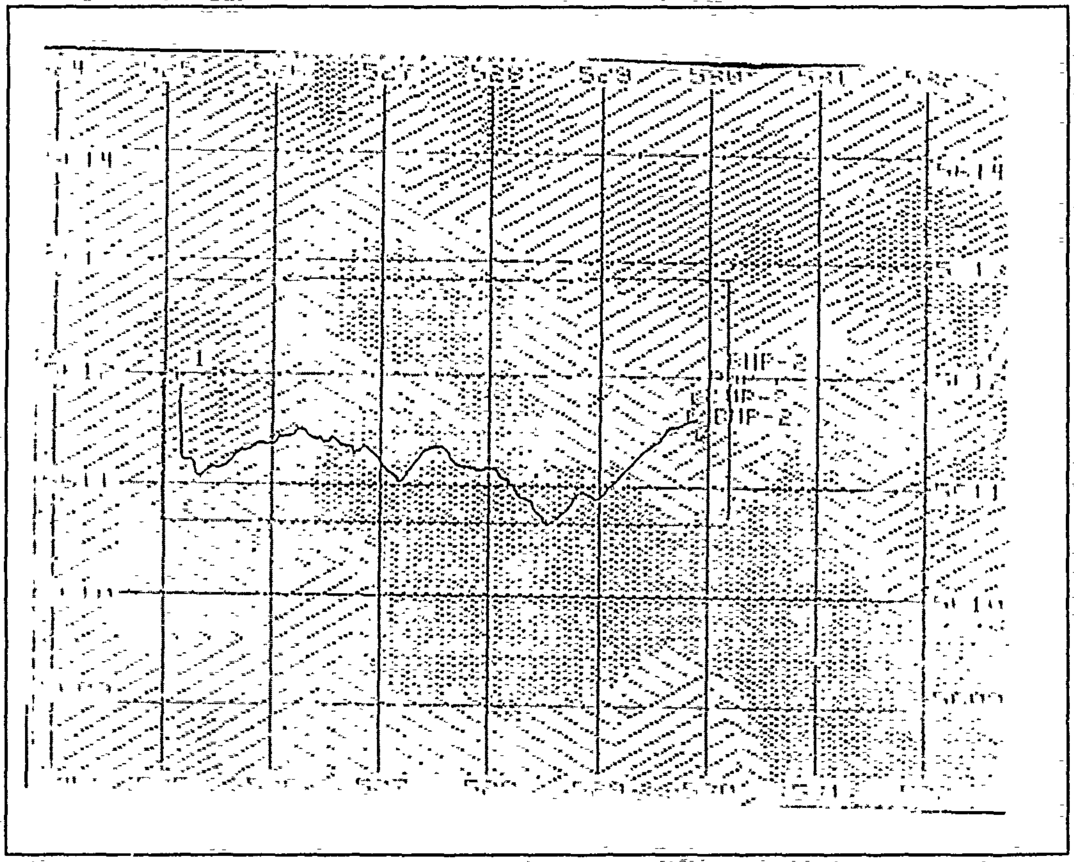


Figure 21 CAMMS/Shaw route with 50 minute avoidance time/4 BMP.

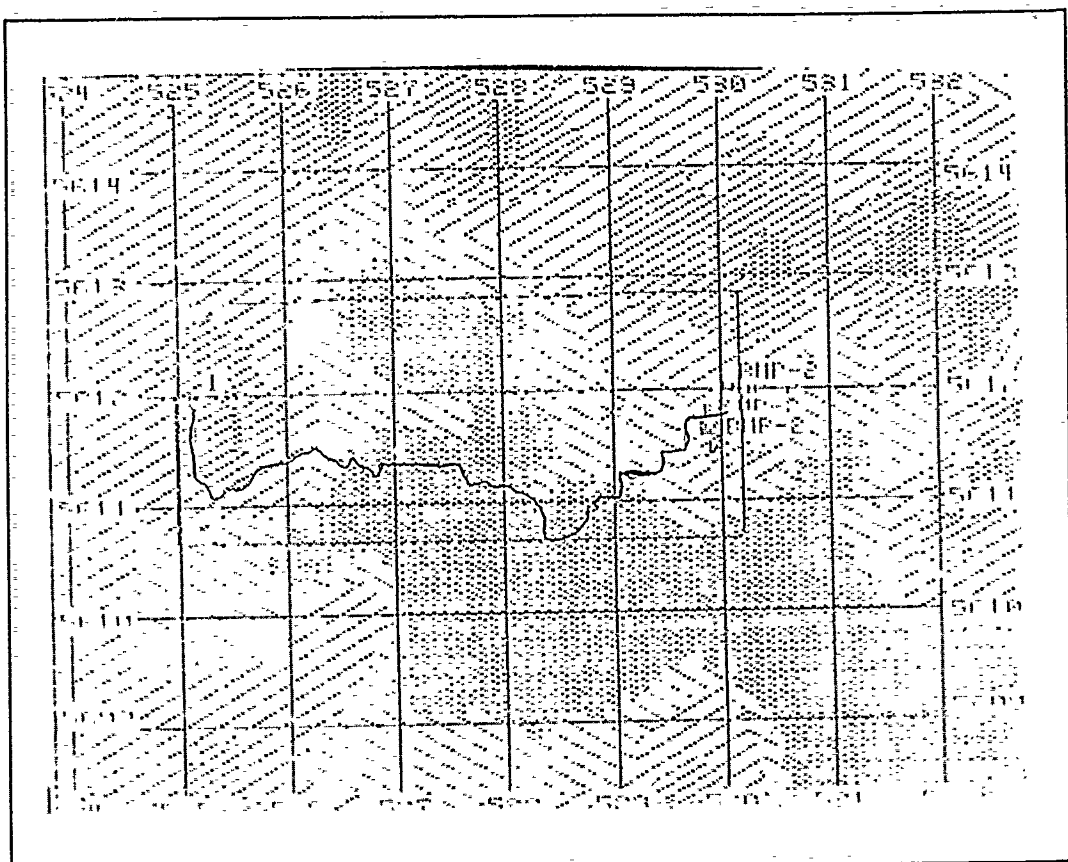


Figure 22 CAMMS/Shaw route with 60 minute avoidance time/4 BMP.

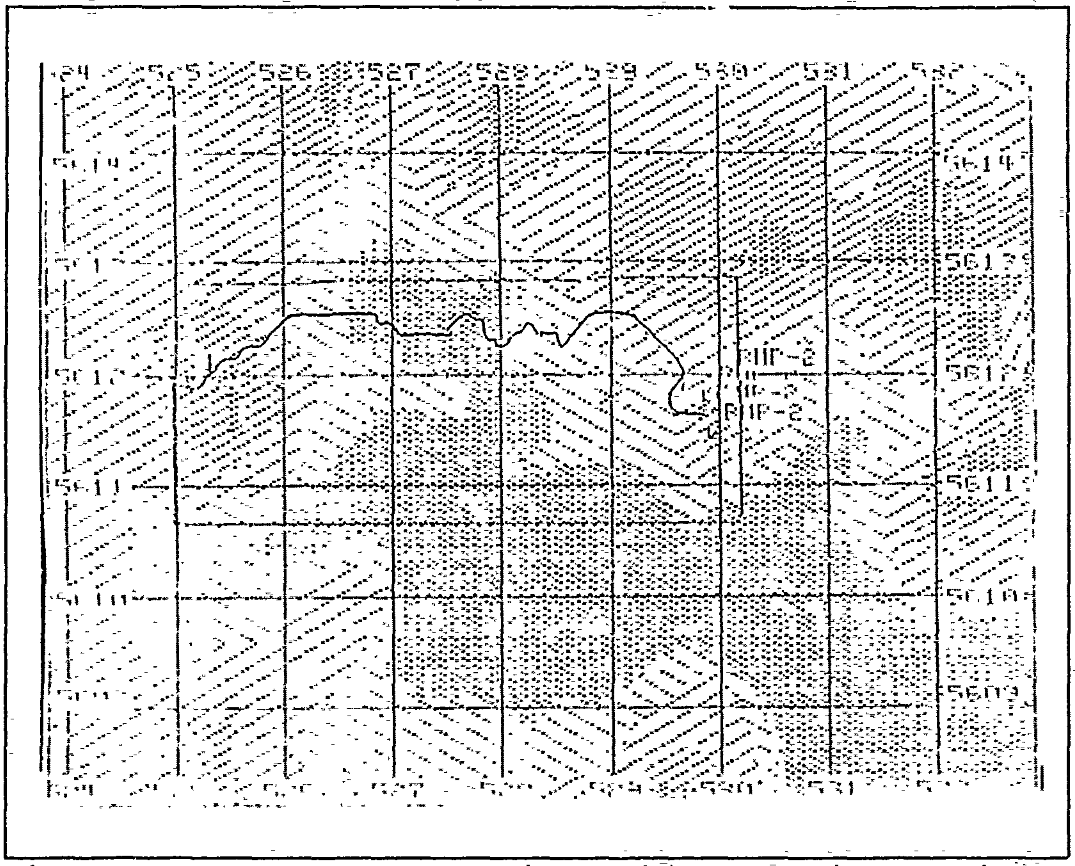


Figure 23 CAMMS/Shaw route with 75 minute avoidance ،ime/4 BMP.

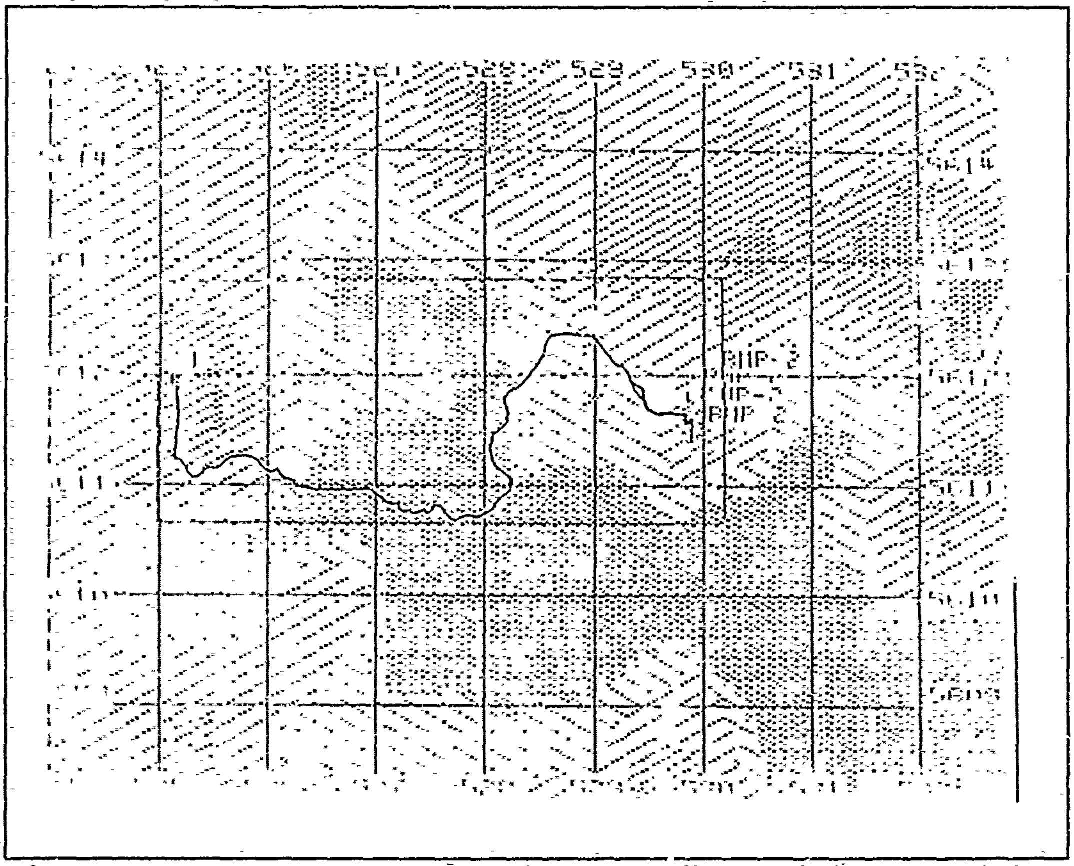


Figure 24 CAMMS/Shaw route with 90 minute avoidance time/4 BMP.

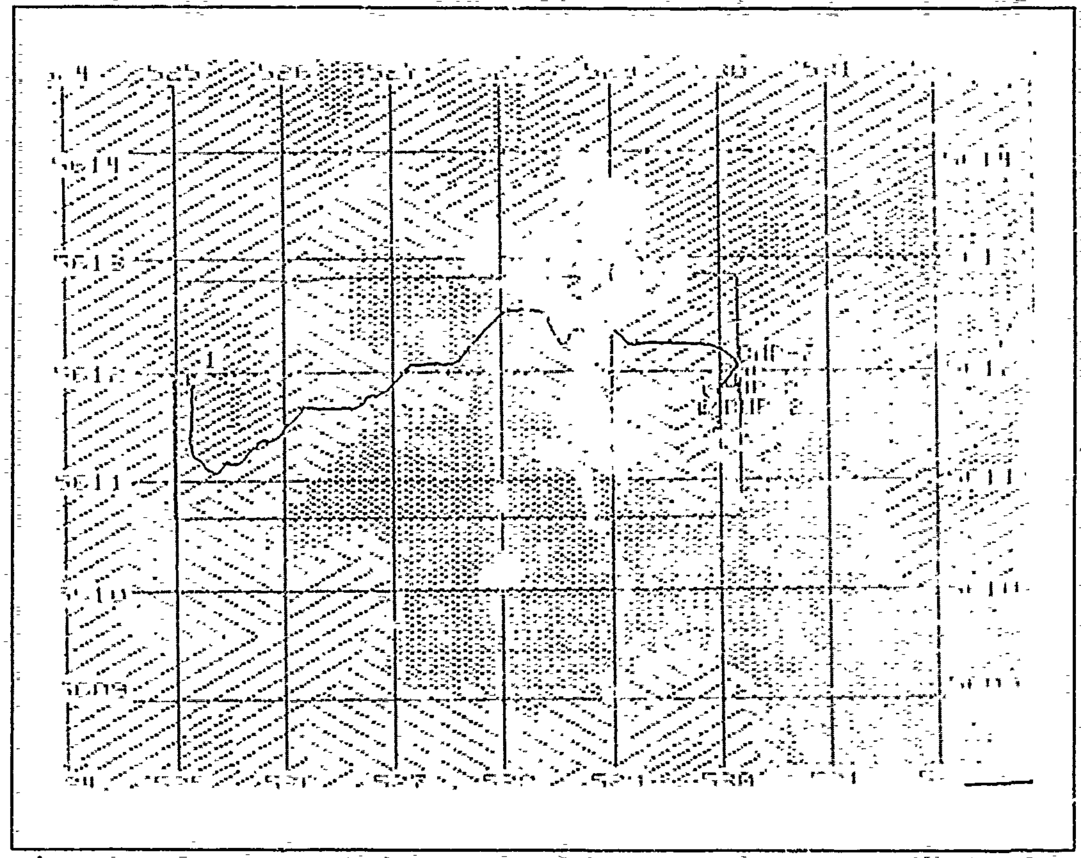


Figure 25 CAMMS/Shaw route with 135 minute avoidance time/4 BMP.

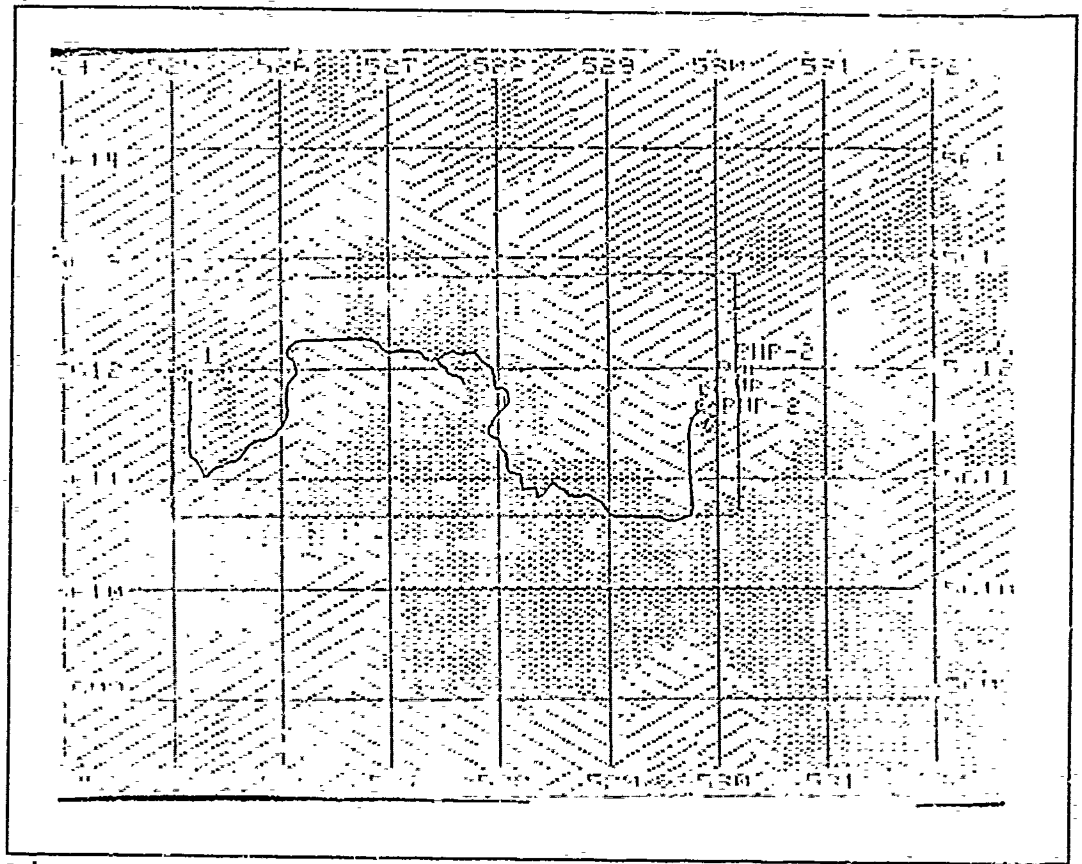


Figure 26 CAMMS/Shaw route with 200 minute avoidance time/4 BMP.

LIST OF REFERENCES

1. Shaw,Charles, *A Psychometric Method For Determining Optimum Tactical Paths In Combat Decision Making And Analysis*, M.S. Thesis, Naval Postgraduate School, CA, September 1989.

2. Lindsay, Glen F., *Constructing Interval Scales From Categorical Judgements*, Unpublished Paper, Naval Postgraduate School, Ca., September 1981.

3. Clark, Gordon, and Bishop A., *The Tank Weapon System*, Ohio State University, 1969.

4. Kramer, James S., *Simulation of Dynamic Tactical Route Selection with Application in the Star Model*, M.S. Thesis, Naval Postgraduate School March 1979

5. Hartman, James K., *Lecture Notes In High Resolution Combat*, Naval Postgraduate School,1989.

6. Aho, Alfred V., Hopcraft, John E., and Ullman, Jeffrey D., *Data Structures And Algorithms*, Addison Wesley Publishing, 1987.

7. Pimper,Jeffrey and Dobbs, Lauri, *The Janus Algorithm Document*, Lawrence Livermore Laboratories, 1988.

8. Gibbons, Jean D., *Nonparametric Methods For Quantitative Analysis (Second Edition)*, American Science Press, Inc.,1985.

9. Stallings, Joseph L. and Clark, Michael G., *Janus(A) Basic User's Manual (Draft)*, TRAC-Monterey, 1990.

10. Hoffman, James , *Janus(A) Laboratory Notes, Lessons 1 to 6*, Naval Postgraduate School, 1990.

11. Pimper, Jeffrey E., Calloway, Dianne R., *The Janus Simulation Guide Version 4.04* Lawrence Livermore National Laboratories, 1989.

BIBLIOGRAPHY

Aho, Alfred V., Hopcraft, John E., and Ullman, Jeffrey D., *Data Structures And Algorithms,* Addison Wesley Publishing, 1987.

Chambers, John M., Clevland, William S., Kleiner, Beat, and Tukey, Paul A., *Graphical Methods For Data Analysis,* Wadsworth Statistics/Probability Series, 1983.

Choi, Seok Cheol, *Determination of Network Attributes from a High Resolution Terrain Data Base,* M.S. Thesis, Naval Postgraduate School, March 1987.

Clark, Gordon, *and Bishop A., The Tank Weapon System* , Ohio State University, 1969.

Crawford, Paul M., *Dynamic Study of Factors Impacting on Combat Power,* M.S. Thesis, Naval Postgraduate School, March 1986.

Gibbons, Jean D., *Nonparametric Methods For Quantitative Analysis(Second Edition),* American Science Press, Inc.,1985.

Hartman, James K., *Lecture Notes In High Resolution Combat,* Naval Postgraduate School,1989.

Hoffman, James, *Janus(A) Laboratory Notes, Lessons 1 to 6,* Naval Postgraduate School, 1990.

Kilmer, Robert A., *The Generalized Value System and Future State Decision Making,* M.S. Thesis, Naval Postgraduate School, March 1986.

Lindsay, Glen F., *Constructing Interval Scales From Categorical Judgements,* Unpublished Paper, Naval Postgraduate School, Ca., September 1981.

Myers,Raymond H., *Classical And Modern Regression With Applications, Duxbury Press, 1986.*

Pimper, Jeffrey E., Calloway, Dianne R., *The Janus Simulation Guide Version 4.04* Lawrence Livermore National Laboratories, 1989.

Shaw,Charles, *A Psychometric Method For Determining Optimum Tactical Paths In Combat Decision Making And Analysis,* M.S. Thesis, Naval Postgraduate School, CA, September 1989.

Shaw, Charles A., *Avoidance Time Ranges,* telefax dated 13 September 1990.

Stallings, Joseph L. and Clark, Michael G., *Janus(A) Basic User's Manual (Draft)*, TRAC-Monterey, 1990.

10. MAJ James Hoffman 1
U.S.Army TRADOC Analysis Command
TRAC-Monterey
Monterey,CA 93943

11. CPT(P) Charles H. Shaw 1
407 Powell Street
Philadelphia, MS 39350

12. Commander and Director 1
USACE-WES
Attn:CEWES-GM (Dr. John Farr)
3909 Halls Ferry Road
Vicksburg, MS 39180-6199